Fall Armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith)- the status, challenges and experiences among the SAARC Member States

Editors

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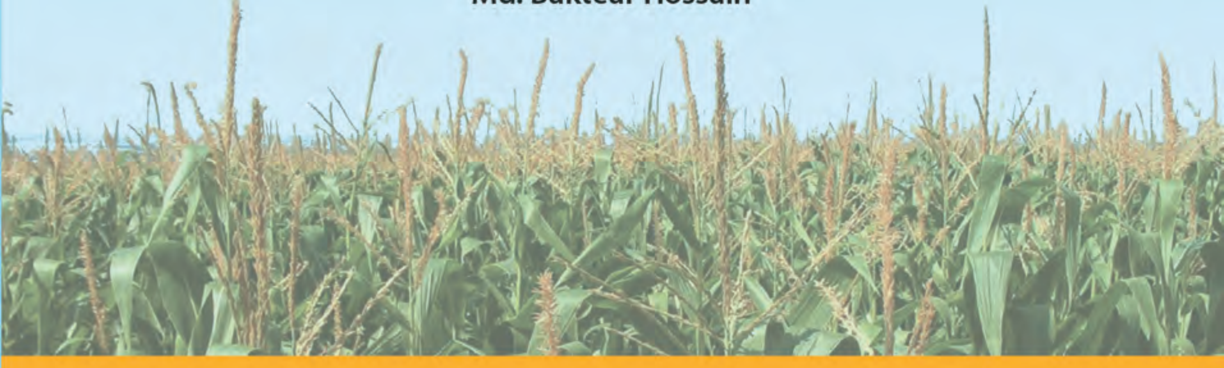

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Regional expert consultation meeting organized by SAARC Agriculture Centre (SAC) on Fall Armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith) - the status, challenges and experiences among the SAARC Member States (virtual), 27-28 January, 2021.

Edited by

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This book '*Fall Armyworm (FAW) Spodoptera frugiperda (J. E. Smith) - the status, challenges and experiences among the SAARC Member States*' *contains the papers and proceedings of the virtual regional expert consultation meeting focusing on Fall Armyworm (Spodoptera frugiperda), its impact on crop production, updated status and strategies for FAW management in SAARC countries organized by the SAARC Agriculture Centre (SAC), Dhaka, Bangladesh. The experts for country papers presentation were the representative of their respective governments. Other experts invited for technical paper presentation were spoken in their personal capacity and on behalf of their respective organization. The opinions expressed in this publication are those of the authors and do not imply any opinion whatsoever on the part of SAC, especially concerning the legal status of any country, territory, city or area or its authorities, or concerning the delimitation of its frontiers or boundaries.*

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FOREWORD

Fall Armyworm (FAW) arrived the Indian subcontinent in May-2018 and now has spread across India, Nepal, Bangladesh, Sri Lanka and approaching more beyond South East Asia. Strong flying capacity, climate adaptability, and wide host range makes them a better colonizing agent than other species of armyworms. Despite maize being primarily infested in this region where it could complete its life cycle, random infestation on sugarcane, sorghum, cotton and cabbage have already been reported from India, Bangladesh and Sri Lanka. I do evidently realize that advanced technologies in the field of Plant Protection and Integrated Pest Management can effectively control the FAW, further to improve the crop productivity significantly and contribute to increased incomes of farmers.

Farmers need significant support to manage FAW sustainably in their cropping systems through Integrated Pest Management (IPM) activities. There is still an urgent need to continue to generate widespread awareness and to empower the farming communities with knowledge of the pest, along with suitable technologies/management practices for its sustainable management in this region. Especially the exchange of information within this region will be very much helpful for the researchers as well as for the extension workers to combat the pest, cost-effectively.

I take the privilege and great opportunity to congratulate Dr. Sreekanth Attaluri, Senior Program Specialist (Crops), Dr. Md. Baktear Hossain and the entire team of experts of eight South Asian countries, eminent resource persons who greatly contributed and deliberated on the topic, and all others who worked for the successful compilation and completion of this valuable book. I would also like to thank all authors for their enthusiastic contributions. I am confident enough that this book will impress upon the policy planners and stakeholders in Crop Production sector in upholding the goals and targets as envisaged in the Sustainable Development Goals (SDGs)-2030 of the United Nations.

I wish all success and long live the spirit of SAARC.

Dr. S. M. Bokhtiar
Chairman
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PREFACE

Fall Armyworm (*Spodoptera frugiperda*), is a trans-boundary insect with a high potential to spread rapidly due to its natural distribution capacity and opportunities presented by international trade. Fall Armyworm (FAW) represents a real threat to food security and livelihoods of millions of smallholder farmers. FAW has spread across all of sub-Saharan Africa, the Near East and Asia. The Fall Armyworm, an important crop pest native to the Americas, was first formally reported in Africa in January 2016, and subsequently confirmed in more than 40 countries.

Given the importance to control the pest in the region, SAARC Agriculture Centre (SAC) organized the Virtual Regional Expert Consultation Meeting on *"Fall Armyworm – the status, challenges and experiences among the SAARC Member States"* to assess the extent of spread or existence of the pest in South Asia. The country status papers and technical paper presented during the meeting by the National Focal Experts of South Asian countries were incorporated in this book. The country status papers revealed the pivotal roles played by various National and International organizations contributing to improvement of rural livelihoods through effective Integrated Pest Management (IPM) practices.

This book '**Fall Armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith) - the status, challenges and experiences among the SAARC Member States'** is published to share information on the status of the pest in the region and also covers the issues and challenges in managing the pest, which can help to review and develop policies for developing sustainable agriculture. It helps to study the requirement of adequate institutions, strengthen sustainable management approach, research and extension support service and capacity development at various stages of crop production cycle to the farmers and technicians.

Md. Baktear Hossain
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CONTENTS

Chapter 1

Sustainable development through integrated pest management practices of Fall Armyworm in South Asian Countries

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1. Introduction

Fall armyworm (FAW), *Spodoptera frugiperda* J. E. Smith (Lepidoptera: Noctuidae) pose a threat to food security and livelihoods of South Asian people as it is a trans-boundary insect capable of moving rapidly due to its natural distribution capacity and through international trade. As it is evident that Fall Armyworm arrived on the Indian subcontinent in May-2018 (Ganiger *et al*., 2018), and spread to atleast five South Asian nations due to strong flying capacity, climate adaptability, and wide host range. It has spread across India, Nepal, Bangladesh, Sri Lanka and in Pakistan further approaching more beyond South East Asia. By the end of 2018, FAW was spread to Bangladesh and Myanmar and in January 2019 in Thailand, Vietnam and China (FAO, 2018a). Maize crop is being primarily infested by Fall Armyworm in the South Asian region (Kumela *et al*., 2018), in addition to infestation on sugarcane, sorghum, cotton and cabbage. The pest is capable of migrating long distances on prevailing winds and can also breed continuously in areas that are climatically suitable. Farmers need significant support to manage FAW sustainably in their cropping systems through Integrated Pest Management (IPM) activities. Awareness of the pest to the farmers is the key for sustainable development in South Asia. Suitable technologies/management practices for FAW management could pave way to control the pest and help in increased crop productions and incomes of farmers. The exchange of information within the region will be very much helpful for the researchers as well as for the extension workers to combat the pest cost-effectively.

2. Integrated Management of Fall Armyworm

Development of sustainable management tools and integrated pest management strategy could prove useful in controlling the spread of invasive Fall Armyworm. In some South Asian countries, chemical insecticides for effective control of FAW have been widely used in the form of seed treatment and foliar sprays as an emergency response to minimize the spread and damage to crops. But this could lead to increased cost of production to growers. It cannot be ruled out that the insecticide resistance in Fall Armyworm populations may increase over a period of time if chemical insecticides are widely used. Insecticides can cause adverse effects to humans, non-target organisms and environment. Therefore, it is pertinent to adopt biological control methods, cultural methods and host plant resistance-based strategies for controlling the FAW on crops, thereby leading to increased crop production and with reduced costs incurred on production.

The importance of conducting On-farm trials (OFTs) to study the pest control has gathered momentum in several South Asian countries particularly using cultural practices, installation of sex pheromone traps, foliar sprays (like neem oil), microbial biopesticides, and need based insecticidal sprays based on economic thresholds varying with crop growth stages. Following intercropping methods/systems, helps in minimizing the crop loss and spread of the pest. Intercropping Maize with non-host crops may be useful to minimize the invasion of FAW (FAO, 2018b). Pest surveillance, using biological control methods, development of high yielding climate resilient hybrids in crops with inbuilt resistance to pests particularly FAW could help boost the yields of crops in South Asia. Agro-ecological approaches such as diversifying intercrops and trap crops should be integrated in controlling the FAW damage as they are eco-friendly, target specific and improve resilience in a sustainable way. Early detection of FAW and formulation of appropriate IPM strategies can help in restricting the movement of the migratory pest in South Asia. Exchange of information, conducting awareness campaigns of the pest and public-private partnerships can minimize the impact of crops loss due to FAW.

3. Way Forward

The pest incidence in several South Asian countries has caused great concern to the farming communities, producers, consumers and policy makers. In order to find solutions to control the menace of the FAW in South Asia, a regional consultation meeting was held in the year 2021 to discuss on the way forward by the participants of SAARC Member States. The following points emerged from eight country discussions on a regional platform

- Many experts in South Asia were in an opinion to strengthen surveillance, research and extension of FAW particularly on Maize and potential non-maize host crops while developing biologically intensive integrated pest management (IPM) programs against FAW. This will be an important step to deal with the pest and to curtail its spread to the countries that are not affected.

- Collective actions of the experts especially from the research departments shall formulate strategies that can find ways for minimising the risk of crop loss due to the FAW. The Member States representatives could support the evolution of national FAW task forces into standing cross-sectorial invasive pest species committees capable of developing strategies and action plans for respective SAARC Member States.
- It is important to develop and establish mechanisms to communicate uniform FAW management recommendations through appropriate disseminating channels in rural areas of SAARC Member States. Most of the extension agencies in different countries were successful in disseminating farmer supportive information and which can be adopted in the case of FAW.
- One of the key control measures of FAW was to use appropriate seed treatment methods which could be popularized along with approved seed treating agents that will be made available to farmers.
- Bilateral and / or multilateral MoUs among SAARC Member States needs to be developed for exchange of information, capacity building and bio-control agents in line with the Nagoya protocol on Access and Benefit Sharing (ABS). It will be an important step for the countries to share and implement the technologies developed by some of the South Asian countries.
- Developing resistance in hybrids against the FAW and stable FAW tolerant/resistant genotypes need to be identified and exchanged in collaboration with International organizations and between SAARC countries developing cultivars with native genetic tolerance or resistance.
- Other areas of developing strong capacities for controlling FAW are to build 'local' capacities in SAARC Member States for extension personnel and maize / non-maize growers in partnership with local and International organizations.
- The development of appropriate, demand-driven and common digital tools for monitoring, advisory, and forecasting of FAW is important in South Asia as it can help check the spread of the pest and update the status of its prevalence in the region.
- In the South Asian countries mass production protocols for biopesticides and the multiplication of bioagents at the community level and above

would be of immense benefit as it will help farmers to reduce the cost of production and effectively controlling the FAW.

- The harmonization of registration of biopesticides across Member States and SAC could be coordinated through regular consultation meetings of network members of respective pesticide registration committees. The concerned agencies of Member States of SAARC need to consider emergency licensing of bio-agents (where one country already registered the bio-agent) and in order to send to other Member States.
- Natural enemies of FAW from similar agro-ecological zones may be collected and catalogued. Sharing of information on potential for FAW control among SAARC Member States.
- SAARC Agriculture Centre (SAC) based in Dhaka is recommended to act as coordinator for collaborative research and to facilitate the exchange of information across Member States of SAARC in technical partnership with National and International organizations.
- FAW response networks need to be strengthened among the SAARC Member States through FAW projects, institutions, and nominated nodal persons from each SAARC Member State to share data on the status of FAW and appropriate IPM technologies, which may also be linked to the SAC web portal.

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Chapter 2

Status of Fall Armyworm in Afghanistan

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1. Introduction

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is native to the Americas, from as far south as La Pampa, Argentina, to as far north as southern Florida and Texas, USA. Fall armyworm caterpillars are major pests of cereals and forage grasses, and recorded as eating 186 plant species from 42 families1. In Florida, fall armyworm is the most serious pest of maize, causing up to 20% yield loss. In areas where less money is available for pest management, impacts are even more severe. The rapid spread throughout Africa was likely due to adult fall armyworm's ability to travel very long distances. Adults can travel several hundred kilometers in a single night by flying and maintaining an elevation of several hundred meters, at which height winds can transport adults in a directional manner. Fall Armyworm's wide distribution in the Americas and Africa suggest that it could establish easily in East and Southeast Asia. Given increasing levels of trade and transportation from infested parts of Africa and the rest of the world, it seems likely that Fall Armyworm could have been transported onwards to environmentally suitable regions.

Insect pests are the major biotic constraints affecting productivity of maize, which in turn threatens food security under changing climate scenarios. In 2016, a new invasive pest, fall armyworm (FAW) *Spodoptera frugiperda* J. E. Smith (Lepidoptera: Noctuidae) prevalent in Americas for several decades was reported for the first time in Africa. Subsequently, in 2018 it was reported in India and fast spread across the continent and beyond. Currently, it has spread to 47 African and 19 Asian countries resulting in crosscutting negative impact by affecting the resource constraint small holders. In India, FAW was first reported in May 2018 from Karnataka and spread rapidly to major maize growing states except Himalayan region. Since then it has been persistent and serious pest of maize in India since 2018 until date. In July 2020, it has been reported from western Himalayan states including Himachal Pradesh and Jammu region of Jammu & Kashmir. Some key points which highlights FAW in the region are as follows:

- Fall Armyworm (*Spodoptera frugiperda*) is an invasive insect pest

- Feeds on more than 300 plant species including wheat, maize, rice, sorghum, sugarcane but also other vegetable crops and cotton.
- Native to the tropical and subtropical regions of American continents.
- However, in 2016 it was reported for the first time in Africa.
- Has now spread to Asia.

2. Global Distribution of Fall Armyworm

Fall armyworm's wide distribution in the Americas and Africa suggest that it could establish easily in East and Southeast Asia. Given increasing levels of trade and transportation between infested parts of Africa and the rest of the world10, it seems likely that fall armyworm could be un-wittingly transported onwards to environmentally suitable regions. In 2018, it invaded Asia. First reports came from Yemen and India and now spread to Bangladesh, Myanmar, Nepal and China. It has diversified diet and can survive harsh conditions by migrating to different places or hiding, to return back during favorable conditions. Its wide dietary platter along with its phenomenal spread across two continents in last two years has made FAW an agent of global food production crisis.

3. Fall Armyworm in Afghanistan

Afghanistan is landlocked country, over 75% of nation is being dependent on agriculture. About 12% of the land is arable and less than 6% currently is cultivated. Normally, Afghanistan grew about 95% of its needs in wheat and rye, and met its needs in rice, potatoes, pulses, nuts, and seeds; it depended on imports only for some wheat, sugar, and edible fats and oils. Fruit, both fresh and preserved (with bread), is a staple food for many Afghans. Agricultural production, however, is a fraction of its potential. Agricultural production is constrained by almost total dependence on erratic winter snows and spring rains for water; irrigation is primitive. Relatively little use is made of machines, chemical fertilizer, or pesticides. The country's major crops are wheat, corn, rice, legume crops including high-value vegetables, fruits and spices. Pests and diseases destroy proximately 30% and 40% of harvests every year.

S. No.	Indicator	2017	2018	2019
1	Wheat	2,104,377	1,635,000	2,534,000
2	Rice	109,452	117,539	127,530
3	Barley	68,179	84,147	84,070
4	Maize	134,225	72,439	94,910
5	Millet	-	-	1,401
6	Pulses	52,243	61,166	67,114
Total Cereals		**2,468,476**	**1,970,291**	**2,909,025**

In case of fall armyworm, Afghanistan is fortunate not to have incidence of FAW so far. Agriculture is crucial for Afghan economy and the country needs to take all care to prevent the pest migrating from neighbouring countries. No survey was done yet, in the country. Furthermore, the country has similar pests on corn, sweetpotato especially in Nangarhar. The Ministry of Agriculture Irrigation and Livestock (MAIL) shall do a wide survey in this regard.

Photo credit: Mohammad Naser Haidar

Figure 1: Technicians discussing with farmers during the evaluation (Plant-wise plant clinics) in 2019 at Nanganhar, Afghanistan

4. Fall Armyworm Environmental Suitability Maps

The following maps show the environmental suitability for fall armyworm and are the result of models created with data on temperature, precipitation and the known distribution of fall armyworm. The maps depict areas, which are environmentally highly suitable in red, and areas, which are environmentally unsuitable in blue.

4. Control Strategies

Chemical insecticides have been widely used in the form of seed treatment and foliar sprays as an emergency response, which in turn resulted in increased cost of production to maize growers. Although insecticides effectively managed FAW, there may be chance of development of insecticide resistance in FAW populations and adverse effects to humans, non-target organisms and environment. In Afghanistan in case of armyworm, farmers also try to use pesticide to control the pest. Recently, farmers use IPM methods to control the disease not only armyworm but in case of all cases after establishment of plant clinics in Afghanistan.

4.1 FAW Integrated Management Options

1. Scouting, Surveillance & Early warning
2. Pesticides
3. Biological Control
4. Cultural Control
5. Host Plant Resistance
6. Policies & Regulations

4.2 Proposed plan

1. Early detection of the pest in any of the provinces of Afghanistan.
2. Need based survey is necessary and time to time monitoring contacting the growers.
3. Arrangement of trainings for farmers and impart knowledge on early detection and advocate necessary control measures
4. Early warning system could be made available.
5. Sharing information to local formers about the fall armyworm.
6. Control strategies based on IPM.

The literature review and the experiences from other invaded countries shows that, early warning system is very crucial in Afghanistan. Recently, Fall Armyworm had been reported in Pakistan and which has been detected near to the Nangarhar province. Furthermore, early warning, information and controlling of Fall Armyworm seminars, workshops and awareness is very much required both to the technicians and farmers in Afghanistan.

Emphasis on pest surveillance, development of high yielding climate resilient hybrids with inbuilt resistance to insect pests with special reference to FAW by use of improved crop nutrition, biocontrol agents, Agro-ecological approaches such as diversifying intercrops and trap crops should be integrated in mitigating the FAW damage as they are eco-friendly, target specific and improve resilience in a sustainable way. Appropriate training of farmers and extension agents in this regard is very much essential. It may be noted that several bio pesticides has showed potential at laboratory or small-scale trials but their affectivity at large scale deployment, mass production, packaging and transport needs to be standardized before bringing these tools for large-scale control of FAW.

Acknowledgement

Authors would like to thank the SAARC Agriculture Centre for organizing the Regional Consultation Meeting on Fall Armyworm and Member countries participation.

Chapter 3

Fall Armyworm- Status, Challenges and Experiences in Bangladesh

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1. Introduction

Maize (*Zea mays* L.) is one of the most important food grains in Bangladesh grown year-round predominantly by smallholder farmers. In Bangladesh, maize is cultivated approximately in 5.59 lac hectares of land producing 55.4 lac tons of maize. Yield potentiality of Maize in Bangladesh is low compared to other countries. This may be due to several abiotic and biotic constraints. Among the biotic factors, different insect pests cause serious damage to maize crops every year in Bangladesh resulting huge yield loss. Prodhan *et al*., 2020, listed 12 species of insect pests including invasive Fall Armyworm (FAW) to be injurious to maize crop in Bangladesh. The devastating insect Fall Armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) was first reported in Bangladesh during November 2018. In South Asia, the FAW was detected for the first time during May 2018 infesting maize crop in Karnataka state of India (Ganiger *et al*., 2018). The pest is becoming a major threat causing substantial yield losses on maize in the region (Kumela *et al*., 2018).

Native to the tropical and subtropical region of America, the Fall Armyworm, is now widespread across the globe (CABI, 2020). The FAW is a most destructive crop pest, known to attack more than 353 plant species across the globe (Montezano *et al*., 2018) but maize is its most preferred host. FAW larvae damage the crop at different stages of growth, from early vegetative to physiological maturity. It can cut down young plants and can also damage leaves, giving them a ragged, torn appearance. The pest feeds inside whorls and can destroy silks and developing tassels. FAW can also feed on developing kernels, which can reduce yields through direct losses, exposure of cobs to secondary infection and loss of grain quality and quantity.

Since the occurrence of FAW in Bangladesh, synthetic chemical insecticides have been widely used as emergency responses to minimize damage in maize fields. Most smallholder farmers in Bangladesh however, cannot afford frequent insecticide applications. Furthermore, dependence on chemical insecticides results in the development of resistance to major classes of insecticides, effects on non target organisms, as well as other adverse effects to humans and the environment. This highlights the need for the development of integrated pest management (IPM) strategies that are suitable to Bangladesh smallholder farmers.

The Government of Bangladesh has been extremely responsive about the Fall Armyworm infestation and outbreak. As soon as the pest was detected in India, Bangladesh Agricultural Research Institute (BARI) began monitoring FAW through pheromone traps in May 2018 in different crops across the country. At length, FAW was captured in pheromone traps in November 2018 in the farmers maize field at Sherpur under Bogura district. FAW damage symptoms was also first noticed there at that time. BARI developed and distributed two fact sheets; the first of which was done before fall armyworm arrived in addition to arranging workshops throughout the country. Under Ministry of Agriculture, a National Task Force has been formed comprising relevant stakeholders to oversee the issues related to FAW invasion in maize and other crops. As per directives of the National Task Force, Department of Agricultural Extension (DAE), different Research Institutes especially Bangladesh Agricultural Research Institute (BARI), Bangladesh Wheat and Maize Research Institute (BWMRI) and some universities are working to minimize the loss of maize growers due to the attack of the devastating pest. Different development partners such as USAID, CABI, CIMMYT, FAO etc. are also implementing projects to strengthen capacity to fight fall armyworm in Bangladesh.

2. Present status of FAW Infestation in Maize in Bangladesh

The devastating insect Fall Armyworm (FAW) was first reported in Bangladesh during November 2018 and subsequently it spread to 22 districts till May 2019 (CIMMYT, 2019). By this time, the attack of FAW has been reported from almost all maize growing areas of the country. During the 2019 summer maize cropping season, initial damage from FAW was limited; infestation in the vegetative stage went up to an estimated 30 to 35% of fields across the country. However, the estimated cob infestation was less than 5% for 2019 summer maize cropping season. During Rabi 2019-20 season, percent plant infestation was 20-25 % at early vegetative stage, then the infestation started to decline with very minimum or low infestation of cob (CIMMYT, Bangladesh).

A. Foliage damage at seedling stage

B. Foliage damage at vegetative stage

C. Damage at growing point

D. Tassel damage

E. Immature cob damage

F. Mature cob damage

Fig. 1 (A - F) Symptoms of damage in maize by FAW

3. Important Activities to Combat FAW in Bangladesh

Government of Bangladesh was very much responsive about the FAW infestation and outbreak before the invasion of this cross-boundary pest. Several initiatives were taken for creating the awareness against this pest. The following activities helping the farmers to combat FAW attack in maize in Bangladesh thereby minimizing crop damage.

i) Formation of national task force

Ministry of Agriculture formed a National Task Force on July 2019 to provide appropriate guidelines on Fall Armyworm identification, monitoring, management, communication and training procedures.

ii) Monitoring and infestation status of FAW in maize and non-maize crops

CIMMYT developed an app and conducting monitoring activities with the help of DAE on maize crop. CIMMYT is also conducting monitoring activities on non maize crops with the help of BARI. FAO distributed 12500 pheromone traps, 25000 lures, and 37500 killing strips to the Department of Agricultural Extension (DAE). These monitoring materials were distributed to all areas in Bangladesh and the monitoring of FAW incidence in the maize field was implemented thereby taking appropriate management actions.

iii) Training on FAW

FAO and CIMMYT implemented extensive training programs for major stakeholders such as DAE officers, lead farmers, NGO personnel, input dealers etc. CABI also imparted training to input dealers. DAE, BARI and BWMRI also trained considerable numbers of progressive farmers.

iv) Fact Sheet production

Around 100,000 copies of a Fact Sheet on FAW was published and distributed throughout the country as decided by the National Task Force.

v) Production of booklets, videos and other educational materials on FAW

BARI, BWMRI, DAE, CIMMYT, FAO, CABI produced and distributed educational materials to the relevant stakeholders.

vi) Quick/fast track registration of effective materials to control FAW

Fast track registration of agro-ecologically safe and effective bio-pesticides, viz. sex pheromone lures of FAW, *Spodoptera frugiperda* nucleo-polyhedrovirus (Fawligen, SfNPV) and seed treating agent Cyantraniliprole 60 FS (Fortenza) has been given.

vii) R&D works on the promising bio-control agents against FAW and bio-rational based integrated management of FAW

BARI and BWMRI are implementing extensive research activities for developing sustainable management options with partial funding support from CABI and / or CIMMYT. Agricultural universities in the country are also conducting studies to this end. Bangladesh Rice Research Institute (BRRI) is also studying feeding behavior and other aspects of FAW in rice crop

4. Crops (other than Maize) affected by Fall Armyworm and the extent of spread in the country

Although maize is the most preferred host of Fall Armyworm, but it can also invade diversity of crops. So, it is very essential to monitor this pest in different vegetable crops throughout the country. During rabi 2019-20, FAW population and damage was monitored in two vegetable crops, tomato and cabbage at Rangpur, Bogura and Jamalpur at farmer’s field. FAW population and damage of tobacco plants were only monitored at Gangachara, Rangpur.

No FAW damage symptoms were observed in tomato and cabbage plants at Bogura. No FAW moth catch was also noticed in the pheromone traps in the studied fields at Bogura. However, in other two locations, Rangpur and

Jamalpur infested plants as well as trap catch of FAW moths were recorded. The number of fall armyworm captured per trap and percent fall armyworm infested plant in different crops at RARS, Burirhat and the farmers' field of Gangachora, Rangpur are shown in Figure 2. The highest number of captured fall armyworm adult per trap were recorded in tobacco crop fields (59/trap) and it was followed by tomato and cabbage crop fields (Figure 2A). The highest percent of fall armyworm infested plant were also noticed from tobacco crop fields (11.2%) followed by tomato (2.8%) and cabbage (1.2%) crop fields (Figure 2B).

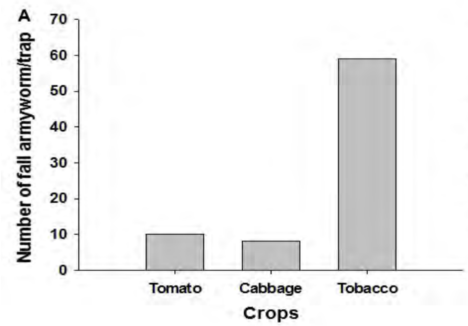

Fig. 2: A. Mean number of fall armyworm captured per trap in tomato, cabbage and tobacco field at RARS, Burirhat, Rangpur and in the farmers' field of Gangachora, Rangpur;

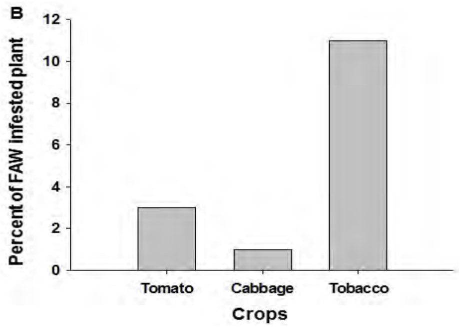

Fig. 2: B. Percent of fall armyworm infested tomato, cabbage and tobacco crops at RARS, Burirhat and the farmers' field of Gangachora, Rangpur during the rabi 2019-20.

However, at Jamalpur the highest number of captured fall armyworm adult per trap were recorded in cabbage crop fields (54.5/trap) followed by tomato crop fields (41/trap) (Figure 3A). The highest percent of fall armyworm infested plants were also noticed from cabbage crop fields (22.8%) followed by tomato (2.9%) crop fields (Figure 3B).

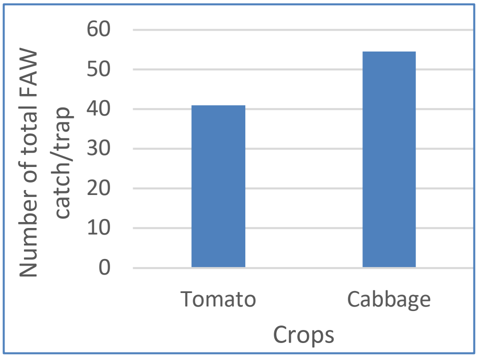

Fig. 3: A. Mean number of fall armyworm captured per trap in tomato and cabbage

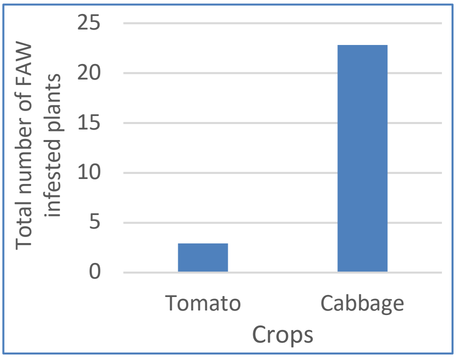

Fig. 3: B. Percent of fall armyworm infested tomato and cabbage crops at RARS, Jamalpur during rabi 2019-20

Fig.4 A. FAW infested tobacco leaf **B.** FAW catch in tobacco field

(Rabi 2019-20, Rangpur)

Fig. 5 A. FAW infested cabbage leaf **B.** FAW catch in cabbage field

(Rabi 2019-20, Rangpur)

Fig.6 A. FAW infested tomato leaf **B.** FAW catch in tomato field

(Rabi 2019-20, Rangpur)

5. Suggested Management Strategies of FAW in Maize

Attempts to control FAW in Bangladesh currently entail excessive use of insecticides by our farmers. Farmers mostly spray Lambda-cyhalothrin, Chlorpyrifos, Emamectin Benzoate, Chlorantranitiprole + Thiamethoxam. But in most cases farmers are not getting satisfactory results by spraying these toxic chemical insecticides. The increased use of pesticides to control FAW in Bangladesh raised concerns for health and environmental risks resulting in a growing interest in research on IPM and biological control options for smallholder farmers.

However, the following management strategy is being pursued by the Government for sustainable management of this pest:

i) Seed treatment: Before sowing, maize seeds should be treated with Cyantraniliprole 60 FS (Fortenza) @ 2.5 ml / kg seed

ii) Installing FAW sex pheromone traps @ 30-35 /ha just after seed sowing in the field.

iii) During visible infestation symptom, hand picking of egg masses or neonate larvae should be done & kill them mechanically.

iv) Flood irrigation is preferable during the time of irrigation at the infested fields.

v) Need based spray of bio-pesticides Sf NPV (Fawligen) or Spinosad (Tracer 45 SC or Success 2.5 SC)

vi) Although chemical pesticides are not so much effective against FAW, but in case of emergency the less toxic pesticides e.g. Ememectin Benzoate 5 SG or Chlorantraniliprole 18.5 SC can be applied.

vii) Crop rotation should be practiced in severely infested areas.

6. Advances in research towards developing sustainable management strategies

BARI Entomologists have already conducted some lab and field studies on different aspects of FAW management. However, BWMRI and some agricultural universities have also some research findings on this aspect. Some important findings in research towards developing sustainable management strategies are given here.

i) Molecular characterization of potential strains of FAW

Molecular characterization as done by BARI of the four isolates of Fall Armyworm by CO1 sequencing indicated all the tested isolates were under the

Spodoptera genus. Phylogenetic analysis comparing with publicly available CO1 sequences from different country revealed that all the four isolates were identified as *Spodoptera frugiperda* (Fig.7). Molecular characterization of FAW in Bangladesh was also done by FAO.

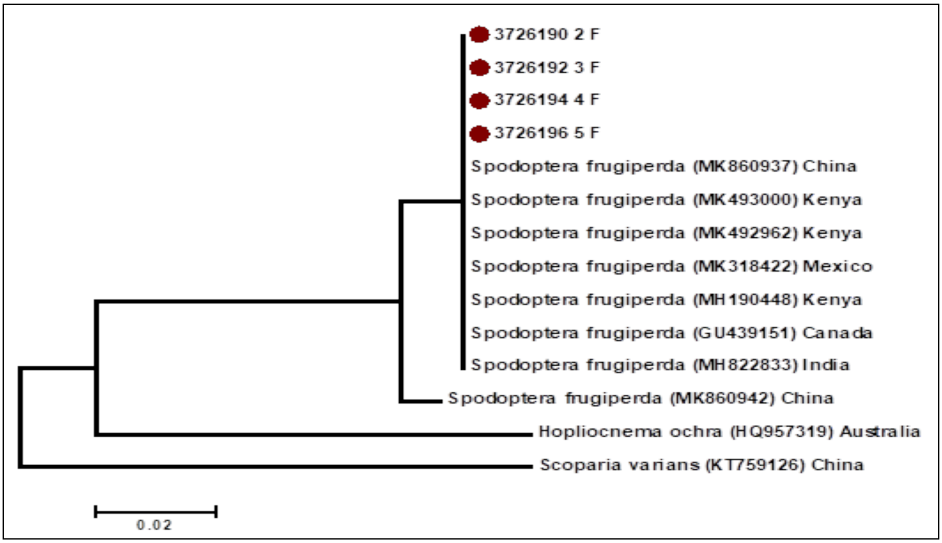

Fig. 7 Phylogenetic tree (Linear) for CO1 genes of the *Spodoptera* isolates. Numbers in parentheses indicated the accession numbers in Gene Bank. The bar represents sequence divergence.

ii) Fall Armyworm mass rearing protocol development

BARI studied the effect of different natural and artificial diets on growth and development of Fall Armyworm (FAW). FAW female moth reared on ICIPE diet laid the highest egg mass (3.8/female) with 44.05% hatchability (Begum *et al.*, 2020).

iii) Lab bioassays to test the efficacy of *Tricogramma chilonis* and *Bracon hebetor*

BARI recently conducted Lab bioassays to test the efficacy of *Tricogramma chilonis* and *Bracon hebetor* against FAW eggs and larvae, respectively. Parasitism differences of *Tricogramma chilonis* were observed among the three types of egg masses under this study, on an average parasitism were 12.54 ± 0.25%, 8.96 ± 0.38%, and 5.26± 0.17 % for egg masses with one, two, and three layers, respectively (Table 1). On the other hand, it was observed that, *B. hebetor* parasitized 100% FAW larvae but no *B. hebetor* emerged from parasitized larvae (Table 2).

Table 1. Parasitism efficiency of *Trichogramma chilonis* on *Spodoptera frugiperda* egg masses under netted condition in laboratory during Nov. 2020 at BARI, Gazipur

Treatments	Actual number of eggs (Mean± SE)	Parasitism (%) (Mean±SE)
One layer	218.00±10.26	12.54 ± 0.25
Two layers	274.67±16.83	8.96 ± 0.38
Three layers	335.00±22.33	5.26± 0.17

Table 2. Parasitization of *Bracon hebetor* on *S. frugiperda, Galleria mellonella* and *C. cephalonica* under laboratory conditions, at Entomology division BARI, during November 2020

Host insect	*B. hebetor* adults/jar	Parasitization (%)	No. of *B. hebetor* larvae formed/ host larva (Mean ±SE)	No. of *B. hebetor* pupae formed/host larva (Mean ± SE)	No. of *B. hebetor* adults emerged/host larva (Mean ± SE)
G. mellonella	10 pairs	100	6.00±1.16	5.33±0.88	4.67±1.46
S. frugiperda	10 pairs	100	0	0	0
C. cephalonica	10 pairs	100	4.00±1.00	3.67±1.20	3.00±0.58

iv) Survey of natural enemies of Fall Armyworm

BARI has already recorded the five parasitoids from FAW eggs/larvae, some of which are the first records in Bangladesh. These are *Chelonus* sp. (Hymenoptera: Braconidae); *Campoletis chlorideae* (Hymenoptera: Ichneumonidae); *Telenomus remus* (Hymenoptera: Platygastridae); *Cotesia* sp. (Hymenoptera: Braconidae) and *Netelia* sp. (Hymenoptera: Ichneumonidae). BARI scientists have also recorded spined soldier bug, *Podisus maculiventris* (Hemiptera: Pentatomidae) as a predator of FAW. However, identification of the parasitoids/predators would be confirmed by molecular analysis.

v) IPM package development

Prodhan (2020) evaluated following IPM packages during Kharif 2020. These were:

Package 01: Seed treatment with Fortenza + Sex pheromone mass trapping starting from 15 days after sowing (DAS) @ 35 traps/ ha + Alternate spraying of SfNPV and Coragen 18.5SC;

Package 02: Seed treatment & Sex pheromone mass trapping as package 01 + Alternate spraying of SfNPV and Proclaim 5SG;

Package 03: Seed treatment & Sex pheromone mass trapping as package 01 + Alternate spraying of Tracer 45 SC and Coragen 18.5SC;

Package 04: Seed treatment & Sex pheromone mass trapping as package 01 + Alternate spraying of Tracer 45 SC and Proclaim 5SG. The highest Marginal Benefit Cost Ratio (MBCR) was obtained, from Package 04, which is followed by Package 03. However, other packages also performed well.

7. On-going research activities

BARI and BWMRI are implementing extensive research activities for developing sustainable management options against FAW attack on maize with partial funding support from CABI and / or CIMMYT. Agricultural universities in the country are also conducting studies to this end. Bangladesh Rice Research Institute (BRRI) also studying feeding behavior and other aspects of FAW in rice crop. An outline of the ongoing important research activities at BARI and BWMRI are presented here:

7.1 On-going Research Activities at BARI

a. Field Survey, Collection and identification of native bio-control agents
b. Lab-Bioassays to test the efficacy of biocontrol agents against *Spodoptera frugiperda* in Bangladesh
c. Development of management package(s) against FAW in maize
d. Bio-control based management of FAW attacking maize
e. Field efficacy studies of some bio-pesticides against FAW attacking Maize
f. Monitoring of FAW population and damage of non-maize fields across Bangladesh.

7.2 On-going Research Activities at BWMRI

a. Response of Maize–Legume Intercropping as Push–Pull Technique to Control Fall Armyworm
b. Monitoring and scouting of insect pests on maize and their natural enemies
c. Development of management package(s) to control FAW on maize
d. Effect of seed treatment with Cyantraniliprole (Fortenza 60FS) to control Fall Armyworm on maize
e. Agro-ecological approaches of FAW management on maize

8. Recommendations

i) Strengthening surveillance and monitoring of FAW on maize and non maize crops across different agro-ecological zones

ii) Strengthening research for developing bio-pesticide based IPM technologies against FAW.
iii) Necessary steps should be taken to popularize seed treatment against FAW and approved seed treating agents should be made available to our farmers.
iv) Natural enemies of FAW from different agro-ecological zones may be collected and catalogued, mass reared and made available with a view of exploring possible use of suitable candidates.
v) Extensive training programs for extension personnel and maize growers should be undertaken. Promotional works such as area-wide farmer participatory demonstrations and Farmer Field School approach for effective dissemination of FAW management strategies may be under taken.
vi) Networking of the scientists working in different SAARC countries for exchange of technical expertise on the FAW management strategies.
vii) Developing short term and long term regional strategy for FAW management and enhancing global and regional coordination and cooperation.
viii) Collaboration and coordination among different stakeholders working on FAW such as extension and research organizations, universities, development partners and private sectors should be enhanced.
ix) Strengthening policy and financial support.

9. Conclusions

The government of Bangladesh is committed to boost up maize production in the country. It is encouraging to note that, Ministry of Agriculture, GOB, through the National Task Force played very proactive role to minimize yield loss of maize since the introduction of FAW in Bangladesh and managed the invasion Fall Armyworm in maize through well coordinated approach. However more efforts are needed to manage the devastating pest in light of recommendations, through the active participation of farmers and relevant stakeholders.

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Chapter 4

Fall Armyworm – the status, challenges, and experiences in Bhutan

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1. Introduction

The Fall Armyworm (FAW), *Spodoptera frugiperda* (Smith, 1797), is an invasive pest species native to the Americas that has been spreading rapidly through Africa since 2016 and in Asia since 2018 (Rwomushana, I., 2019; Goergen et al., 2016; Sharanabasappa et al., 2018). FAW feeds on more than 300 species including grains (rice, maize, sorghum), other grasses, many non-grain crops (e.g., soybean, peanut, potato, sweet potato, spinach, tomato, etc.) and can cause devastating losses (Day et al., 2017; Montezano et al., 2018).

Fall Armyworm has been spreading rapidly, it was first spotted in Asia from India in May 2018 (Sharanabasappa et al., 2018). As of 2020, the Fall armyworm has spread to South Asia, Southeast Asia, China and recently in Australia (Lamsal et al., 2020). Once established in a country, FAW is not possible to eradicate or control to stop it from spreading – an adult can fly up to a hundred kilometers in a single night. Based on 2018 estimates from 12 African countries, up to 17.7 million tons of maize could be lost annually due to FAW on that continent – enough to feed tensof millions of people (FAO, 2018). South Asian Association for Regional Cooperation (SAARC) countries are responsible for 3.2% of global maize production (Pandey, P. R., & Koirala, K. B., 2017). FAW can drastically reduce the production, thus adversely affecting the food security in the region.

2. Incidence of Fall Armyworm in Bhutan

In Bhutan, cereal crops such as maize and rice are one of the most important staple crops. Maize is the most cultivated crop in Bhutan. It was cultivated in an area of 32,484. 67 acres followed by paddy which was grown in 4438.16 acres during the fiscal year 2018-2019 (National statistics Bureau, Bhutan, 2020). The incidence of different insect pest species inthese crops is very common. Among them, outbreaks of armyworm species havecaused serious yield losses in the past. For e.g., the Northern armyworm, *Mythimna separata (*Walker*, 1865)* outbreak in 2013 caused severe damage in paddy nursery and later in maize through 18 districts across the country. A swift response using neem and synthetic insecticides in these areas brought the outbreak under control. The outbreak was observed to have been caused by an unusual weather pattern with dry season early on in spring and rains thereafter. The dry period is assumed to have wiped out the natural enemies and with the onset of heavy rain, plant growth was rapid which provided plenty of food for the pest to proliferate. However, no empirical studieswere conducted that supports this assumption.

No activity of Fall Armyworm (FAW) was recorded in Bhutan until its first detection in maize fields in Punakha District, located in the western part of the country, in September 2019 (Mahat et al., 2020). Subsequently, FAW outbreaks were observed in maize crops in the Southern parts of the country, located in Chukha and SarpangDistricts in December 2019 and April 2020 respectively. The preliminary identification was done from the larvae collected from an infested field. Furtherconfirmatory identification of FAW was carried out by rearing them to the adultstage in the laboratory. Confirmatory identification (COI) was carried out using both morphological and molecular techniques. Morphological identification wascarried out using male morphological characters and genitalia dissection. The COI marker was used to further confirm its ID. Molecular analysis indicated it to be the corn strain that prefers to feed on maize plants, unlike the rice strain (Mahat et al., 2020).

3. Crop Affected by Fall Armyworm and the Extent of Spread in the Country

In Bhutan, the Fall Armyworm has been reported only in maize, there has been no report of fall armyworm infesting other crops such as rice, vegetables, and other cultivated crops. The National Plant Protection Center is monitoring the presence of Fall armyworm in the country using pheromone lures as part of the AFACI (The Asian Food and Agriculture Cooperation Initiative) project. The Centre is monitoring the presence of FAW in different crops such as rice, maize, and vegetables. However, due to the Covid-19 situation and travel restriction in the country, the progress of monitoring has been slowed down but will be resumed as soon as the situation improves.

So far, most of the FAW infestation has been observed in mid and low-altitude areas, which experiences warm climatic conditions. Though confirmatory studies have not been conducted, it is assumed that FAW is yet to be established in the cooler parts of the country. This is because, FAW is a pest of tropical origin, unable to undergo diapause or survive cold conditions (Du Plessis et al., 2020;

He et al., 2019). Therefore, in Bhutan, it may not survive year-round in the cold winters or overwinter in the temperate regions such as northern and central Bhutan. However, FAW might have established as a permanent, multigenerational pest in the southern region of the country which has a subtropical climatic condition from which it might migrate to the interior, cooler temperate regions of the country with the availability of host plants, and onset of favourable climatic conditions (Mahat et al., 2020).

While there has been a limited infestation observed in the country as of now, which is mainly restricted to mid and low altitudes, but it caused severe damage to the maize plant. It has been observed that 90 to 100 percent of the plant were damaged in the FAW infested field. It has been observed that young plants were more susceptible to fall armyworm infestation as compared to the mature plant. Infestation in mature was lower and mature plants were also able to recover from FAW damage. It has also been observed that intervention at the early infestation stage provided good levels of control and if intervened early, the plant could recover from damage, and later a normal growth is observed without any significant loss in the yield.

4. Management of Fall Armyworm through IPM and other practices in Bhutan

The National Plant Protection Centre (NPPC) under the Department of Agriculture (DOA) has developed a guideline for FAW Identification and management. Though the recommended practices have not been field validated, the current recommended practice for the management of FAW in Bhutan includes monitoring adult activity by deploying pheromone traps and with the capture of three adult moths per trap sprays with biopesticides such as neem oil is recommended (Mahat and Zangpo, 2020). For maize, observed damage levels of 10–30% and 30–50% at the early and late whorl stages, respectively, will require pesticide applications. At the final growth stages, the tassel and silk stages, no pesticide spray is recommended, but mechanical control of the larval stages and conservation of natural enemies is advocated (Mahat and Zangpo, 2020). These recommended practices are mostly based on the package of practice developed by FAO and agencies combating FAW in Africa. While interim management practices for FAW have been recommended,the biology, ecology, and occurrence of this pest in Bhutan require furtherinvestigation to develop integrated pest management (IPM) strategies that are suitable in the local conditions for Bhutanese farmers (Mahat et al., 2020).

5. Strategies to control Fall Armyworm and advances in research

Since the detection of FAW, it has been observed that due to the lack of knowledge farmers and other clientele' report the incidence of FAW at the last stage. This makes the control of FAW very difficult. However, in areas where its infestation is reported early control intervention (cover sprays) have been observed to be effective in bringing down the damage levels. However, research and development efforts aimed at developing effective control strategies have greatly been impeded due to the current pandemic.

To effectively manage FAW, some of the following activities must be addressed on a priority basis to reduce the threat posed by FAW in Bhutan:

1. Build capacity for Fall Armyworm identification, monitoring, and managementthrough training and awareness programs.
2. Conduct field studies to understand Fall armyworm population dynamics, phenology, and incidence in Bhutan.
3. Conduct research to understand the incidence of endemic natural enemies and their effect on the Fall armyworm population through mortality caused by egg and larval parasitoids.
4. Conduct field research to develop effective and sustainable management of Fall Armyworm (use of mass trapping using pheromone, the efficacy of botanicals and neem, use of border planting technique of attractive and repellent plants (push-pull technology)).
5. As part of the Global action for FAW initiated by FAO, liaise with FAO for support in capacity building and inception of TCP and/or capacity development projects.

6. Recommendations

1. Establish a network in the SAARC region to share knowledge, experiences, ideas, and tools in managing FAW
2. Active research and development collaboration and support fromestablished institutions and agencies to partner countries in devising toolsto combat FAW
3. Fund and technical support to partner countries for effective FAW management
4. Develop technology in the SAARC region for active surveillance and forecast of pest (e.g., such as the FAO-FAMEWS) to help provide real-time

information on FAW infestation in a location and adjoining areas for early intervention and preparedness.

7. Conclusion

Maize is an essential crop in Bhutan and with the detection of fall armyworm in the country, a concerted effort must be directed in undertaking research and development to understand the biology and develop effective FAW management strategies. As it is a new pest, awareness, and training programs on FAW must be upscaled. Also, enough funds and appropriate projects must be mobilized and developed in managing this pest. There is an urgent need to collaborate with relevant agencies and international institutions in building research capacity in managing FAW in the country. An effective information-sharing platform and use of information technology can enhance research projects on FAW.

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Chapter 5

Fall Armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith)- the status, challenges and experiences in India

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1. Introduction

Maize (*Zea mays* L.) is a multi-faceted cereal crop, commonly known as "Queen of Cereals" due to its highest genetic yield potential. It is a potential crop for enhancing the farmers' income and is one of the most important crops next to rice and wheat. In India, maize is grown in an area of 9.2 million ha in varied agro-climatic conditions with a production of 31.51 million MT. The country represents nearly 4% of the global maize area and 2% of global production. The peninsular India represents nearly 40% of the total maize area in the country producing over 52% of production. Madhya Pradesh and Karnataka are the most important maize growing states representing 14.0 and 13.7% of crop acreage respectively, followed by Maharashtra (12.0%), Rajasthan (9.8%), Uttar Pradesh (8.0%), Telangana (6.1%), Bihar (5.4%), Gujarat (4.7%) and Tamil Nadu (3.8%). On production, peninsular India and north eastern plain zone (eastern Uttar Pradesh, Bihar, Jharkhand, West Bengal and Odisha) together contribute 60% of the rainy and 90% of the post-rainy maize produced in India. Majority of maize is used for poultry and animal feed (60%) and industrial purposes (14%) besides use as food (13%), processed food (7%) and 6% for seed and other purposes. It is cultivated for several purposes like quality protein maize, baby corn, popcorn, sweet corn, silage, fodder and for other industrial products.

Insect pests are the major biotic constraints affecting productivity of maize, which in turn threatens food security under changing climate scenarios. In 2016, a new invasive pest, fall armyworm (FAW), *Spodoptera frugiperda* J. E. Smith (Lepidoptera: Noctuidae) prevalent in Americas for several decades was reported for the first time in Africa. Subsequently, in 2018 it was reported in India and fast spread across the continent and beyond. Currently, it has spread to 47 African and 19 Asian countries resulting in cross-cutting negative impact by affecting the resource constraint small holders. In India, FAW was first reported in May 2018 from Karnataka and spread rapidly to major maize growing states except Himalayan region. Since then, it has been persistent and serious pest of maize in India. In July 2020, it has been reported from western Himalayan states including Himachal Pradesh and Jammu region of Jammu & Kashmir. The cumulative data published by Department of Agricultural Cooperation & Farmers Welfare, Govt. of India on June 25, 2019 indicated that Karnataka had highest area affected with FAW (211300 ha) followed by Telangana (24,288 ha), Maharashtra (5,144 ha) and others (Rakshit et al. 2019). The outbreak of FAW has affected maize cultivation to a larger extent as 15 million Indian farmers are engaged in growing of this crop.

2. Crops Affected by FAW and the Extent of Spread in the Country

FAW is a highly polyphagous migratory lepidopteran insect pest reported to feed on more than 350 plant species with a preference to cereal crops across the globe. Other than maize, it has been reported from sorghum and other millets and sporadically on sugarcane, where no substantial economic damage is reported. However, it has the potential to spread to other crops, particularly cotton and vegetables. The host range of FAW in India has been described in Table 1. The insect can complete several generations in a year and likely become endemic to the Indian sub-continent. Most of the economic damage is caused by late instar larvae that feed on maize whorls during vegetative stage, and on maize tassel, silk and cob during reproductive stages. The female moth is a strong flyer and can cover 100 km in one night. Under uncontrolled conditions, FAW had the potential to cause maize yield losses from 8.3 to 20.6 million tonnes per annum (21–53% of production) (Day et al. 2017). The suitable agro-ecological conditions in India such as high humidity and moderately high temperatures always put a challenge to remain continuously vigilant not to allow the spread of FAW to wider areas. In India, the typical planting season is from mid-June to July, mid-November to January and mid-February to March during *kharif*, *rabi* and spring seasons, respectively. In maize growing areas, early plantings result in low infestation of FAW. On the contrary, late plantings increase the pest infestation due to year-round availability of host plants.

3. Information, Education and Communication initiatives taken to tackle the FAW Infestation

During 2018-19, the subsistence farmers and key stakeholders lacked experience and knowledge about the new pest, and its integrated management strategies. Hence, technical briefs on FAW identification, scouting and timely dissemination of a quick action plan to manage FAW has been mooted by ICAR-Indian Institute of Maize Research (ICAR-IIMR), Ludhiana as the urgent need for its effective management. ICAR-National Bureau of Agricultural Insect Resources (ICAR-NBAIR), Bengaluru, ICAR-National Centre for Integrated Pest Management (NCIPM), ICAR-Agricultural Technology Research Institutes (ICAR-ATARI), Department of Agricultural Cooperation & Farmers Welfare (DAC&FW), Department of Post-entry Quarantine (DEPQ) and line departments besides the state agricultural universities in the affected states were close partners in this initiative of capacity building for FAW management. Immediate recommendations given by ICAR-IIMR mitigated the adverse impact of FAW to a considerable extent. Rakshit et al. (2019) documented the initiatives taken by ICAR-IIMR and its AICRP partners since report of FAW in India. Some of the key initiatives are given below:

- A high level meeting on FAW was conducted on August 20, 2018 at Krishi Bhavan, New Delhi. On the basis of the decision, a High Power Committee (HPC) was constituted, headed by the Secretary (DAC&FW) and Secretary (DARE) to review the status and to recommend appropriate strategies. As a follow up each affected states also has such committees under the chairmanship of Principal Secretary or Commissioner to review the situation.
- ICAR has undertaken several initiatives to strengthen capacity of the country to respond to FAW attack through its constituent institutes. All India Coordinate Research Project (AICRP) centres functioning under various SAUs held consultative interface meetings with State Government officials to ensure coordinated response for effective action in response to the rapid outbreak of FAW. AICRP on Maize centres had a total of 89 interface meetings such interface meetings/surveys since 2018. Awareness was also created by field functionaries in the village level by conducting group meetings.
- Further efforts are also going on for proper monitoring, awareness creation and sustainable management of FAW by following IPM strategies. Till now ICAR institutes (ICAR-IIMR, ICAR-NBAIR, ICAR-ATARI Zone X, ICAR Complex for NEH Region) with its coordinating networks have organized 812 major training programmes across the country, where 392 programmes were organized by IIMR and/or its AICRP on Maize partners and benefitting 32,434 stakeholders. These trained persons in turn disseminated the knowledge on this new pest.
- ICAR-IIMR in collaboration with FAO organized twelve virtual training programs on "Integrated pest management for maize crop with special

reference to fall army worm" under the FAO project TCP/IND/3709 on "Time-critical measures to support early warning and monitoring and sustainable management of the Fall Armyworm in India benefitting 1076 personals.

- ICAR-IIMR, ICAR-NBAIR and its AICRP on Maize centres have prepared folders/leaflets/pamphlets on the identification and management of FAW and issued advisories through use of print and electronic media.
- ICAR-IIMR collaborated with the University of Michigan and SAWBO, to translate SAWBO animated video on "FAW Identification, Scouting and Management" into 13 Indian languages.
- ICAR-IIMR in coordination with AICRP on Maize centres distributed pheromone traps with lures for monitoring FAW populations in maize growing ecologies.
- ICAR-NBAIR in coordination with AICRP on Biological centres conducted field days, demonstrations and distributed several potent biocontrol agents for the management of FAW.
- District pest surveillance units of State Department of Agriculture were established for regular survey. Surveillance and monitoring of FAW is being done by Central IPM Centres.

4. Strategies to Control FAW and Advances in Research

ICAR-IIMR initiated experiments under AICRP on Maize and at ICAR-IIMR centers in various aspects for FAW management. To further strengthen the research on FAW, ICAR- National Agriculture Science Fund project on "Development of sustainable management tools for the invasive pest Fall armyworm *Spodoptera frugiperda* (J. E. Smith) in maize" was sanctioned on 1st October, 2019 with outlay of Rs. 302.12 lakhs. In this project ICAR-IIMR is collaborating with ICAR-NBAIR, ICAR-IARI and NIPGR for development of sustainable management tools of FAW.

ICAR-IIMR and ICAR-NBAIR studied morphological and molecular characterization of FAW infesting maize. ICAR-IIMR developed 'integrated pest management strategy and package of practices' for management of FAW in grain corn, sweet corn, baby corn, pop corn, fodder and silage maize (Govt. of India Office Memoranda dt. May 6, Aug 5& 16 and Nov 26 of 2019). FAW recorder, an Android App was developed for surveillance of FAW in collaboration with IASRI (*https://play.google.com/store/apps/details?id=com.icar.iasri.DiseaseTracking&hl=en_IN*). Life history and life-table parameters of FAW have been worked out in tropical Indian conditions. The total life cycle of

FAW was observed to be 30-35 days under laboratory conditions. The results on life-table studies revealed that survival fraction among larval stages of FAW remained highest (0.98) at 5th instar and lowest (0.92) at 1st instar of FAW, while maximum Mortality Survivor Ratio (MSR) (0.09) was observed at 1st instar and minimum MSR (0.01) was obtained at 5th instar. The incidence and damage of FAW was observed in many grass species in maize ecosystem. Hence, an attempt was made to study FAW behaviour in 13 such hosts along with maize. It was observed that the most preferred weed for FAW neonates was *Eleusine indica*, while the most suitable host was *Brachiaria panicoides*. In addition, the survival and development of FAW was evaluated on four different hosts *viz.*, *Zea mays* (maize), *Gossypium hirsutum* (cotton), *Ricinus communis* (castor) and *Brassica oleracea* var. *botrytis* (cauliflower) and a semi-synthetic diet. The shortest life cycle of 32.8 ± 0.52 days in males and 34.1 ± 0.43 days in female was observed on maize, respectively. The semi-synthetic diet was found to be the better with higher mean fecundity (1324.6 ± 61.21 eggs), larval weight (503 ± 0.02 mg), pupal weight (263 ± 0.01 mg) and adult female weight (128 ± 0.0 mg) than natural hosts. Alteration of sowing date is an important cultural practice which can escape the insect pest peak activity. Hence, the effect of different dates of sowing on oviposition and damage of FAW was studied from *rabi* 2018-19 to 2019-2020. The minimum damage of FAW was observed when maize sown during 1st June to 15th June during *kharif* while it was on 15th November during *rabi* season.

ICAR-IIMR identified promising lines namely, DMRE 63 (3.0), MP 704 (3.0), CML 71 (3.0), CML 336 (3.5), *Zea mays parviglumis* (4.0) and CML 346 (4.0) against FAW based on Davis score (1-9 Scale). Furthermore, to determine the mechanisms of resistance against FAW, biophysical (trichome density and relative water content) and biochemical (total flavonoid content) parameters were analyzed in 12 genotypes. Among the lines, the highest trichome density was observed in ENT 2-3 (231.7) followed by NAI 178 (171.8), PFSR R3 (151.1), AEBY 1 (139.1) and CML 71 (128.6) while the lowest trichome density was observed in CM 500 (58.9). Higher total flavonoid content was observed in CML 346 (0.94 mg/g) followed by *Zea mays parviglumis* (0.6 mg/g) and CM 500 (0.6 mg/g) while lowest was observed in E 57 (0.42 mg/g). A non-significant negative correlation (r = -0.5998) was observed between Davis score and total flavonoid content among the genotypes. Early detection through monitoring by pheromone traps is the most important and effective strategy for the management of FAW. Therefore, apart from identifying resistant sources to FAW, slow releasing dispensers developed by ICAR-NBAIR were also evaluated along with other lures available in the market. It was found that ICAR-NBAIR lure is more effective in monitoring FAW populations.

Among biocontrol agents, several entomopathogens developed by ICAR-NBAIR were also found effective against FAW. The natural enemy complex of FAW including egg parasitoids, larval parasitoids and pupal parasitoids were reported. *Glyptapanteles creatonoti* is recorded as gregarious larval parasitoid for the first time across the globe. It is a well established parasitoid of various noctuids in India and Malaysia. (*ICAR-NBAIR Annual Report*, *2018-19*). ICAR-IIMR in collaboration with ICAR-NBAIR identified for the first time *Coccygidium transcaspicum* (Kokujev) as larval parasitoid of FAW (Gupta et al. 2020a). The reported natural enemies of FAW in India are mentioned in detail in Table 2. Four releases of *T. pretiosum* @ 50,000/ha in FAW infested fields along with other IPM interventions (pheromone traps, entomopathogenic fungi and entomopathogenic bacteria) resulted in 76.14 % reduction in FAW egg masses at 60 days after first release (*ICAR-NBAIR Annual Report*, *2019-20*). With respect to microbial insecticides, cry proteins produced by *Bacillus thuringiensis* are effective for the control of wide diversity of insect pests. Therefore, an attempt was made to evaluate the insecticidal activity of thirty-six *Bacillus* strains isolated from various habitats against neonates of FAW. Two strains (VKK-SL2 and VKK-EV) were found to be the most toxic as attained 80% mortality on the 4^{th} day after treatment followed by VKK-LE1 and LE2 (attained 60 and 66% mortality respectively).

The use of botanicals is one of the prime means in protecting maize from insect pests and the environment from pollution. Plant derived pesticides are attractive alternatives to synthetic insecticides, constitute an affordable tool for insect pest management. Therefore, the efficacy of several neem-based insecticides was tested against FAW. Among them, NSKE 20% was found effective against FAW under laboratory conditions. Further, NSKE and Neem Baan (10 ml/l to 2.5ml/l) were tested in sweet corn and baby corn. Ear infestation was lower at higher concentration of the pesticide in both baby corn and sweet corn. In sweet corn significantly higher yield was recorded in Neem ban at 10 and 5ml/l than control. Since the incidence of fall armyworm, farmers from various parts of the country are practicing various indigenous technical knowledge (ITK) practices for its control. Therefore, different ITK practices were evaluated against FAW along with neem-based insecticides in maize under natural infestation. Among the various treatments, application of lime + caustic soda @ 5.0, 7.5 and 10.0 g/l of water recorded lowest percentage of plant infestation (24.1 to 30.0), lowest Davis score (1.9 to 2.1) and lowest number of larvae (3.5 to 5.3). The natural enemies of FAW were high (11.5) in maize treated with dry sand alone. Agro-ecological interventions are a core component of IPM and can be integrated with breeding for pest resistance, biological control and safer pesticides. Therefore, different intercrops have been tested against FAW in various agro-ecologies. It was found that pigeon pea or mung bean intercropping in regular rows (1:1) had the lowest damage by FAW. Highest yield was obtained in maize + pigeon pea (1:1) followed by maize + cowpea (2:2) compared to maize alone.

5. Management of FAW through IPM and other Practices in the Country

As there was a sudden occurrence of alien invasive FAW in India, chemical insecticides have been widely used in the form of seed treatment and foliar sprays as an emergency response to minimize the spread and damage to maize, which in turn resulted in increased cost of production to maize growers. Although insecticides effectively managed FAW, there may be chance of development of insecticide resistance in FAW populations and adverse effects to humans, non-target organisms and environment. Therefore, depending on the geographical location and extent of infestation, integrated pest management strategies are necessary to mitigate the negative impact of FAW in maize agro ecosystems. Cultural and host plant resistance based strategies along with biological control and other biorational approaches significantly reduce dependence on chemical pesticides. This assumes more significance in specialty corn, *viz*., sweet corn, baby corn and fodder maize where the harvests are processed early and often consumed raw or with minimum processing. Pesticide residues in such harvests are supposed to cause health hazards in human beings and animals. First to third instar larvae of FAW are quiet small and eat less 2% of the total foliage consumed in its life cycle, while it is 4.7, 16.3 and 77.2% for the 4^{th}, 5^{th} and 6^{th} instars (Sparks 1979), which heavily defoliate the crop. Thus, if control measures are promptly adopted at the papery window stage economic damage and subsequent pest out break can be prevented. Thus, an IPM package for FAW in maize was made based on the available literature and adapted to small holder farmers of India by ICAR-IIMR in collaboration with ICAR-NBAIR and communicated to various stakeholders.

Principal components of IPM module for FAW management in maize are as follows:

- Selection of single cross maize hybrids with tight husk cover, especially for sweet corn.
- Deep ploughing after harvest of crop to expose FAW pupae to sun light and predators. Under zero-tillage, application of neem cake @ 500 kg/ha to be done. Fields to be kept weed free and balanced fertilizer application to be followed.

- For maximizing plant diversity, intercropping of maize with suitable pulse crops of particular region is advisable e.g. maize + pigeon pea/black gram /green gram. Planting of Napier grass in the border rows to act as a FAW trap crop.
- Hill planting of maize is to be avoided; one plant should be maintained per hill by thinning.
- Application of nitrogen and irrigation after control measures to boost up the crop growth and minimize damage caused by FAW incidence.
- Use of clean cultivation approach by using mechanical or chemical herbicide application.
- Sowing time at community level to follow synchronous planting and planting of maize before arrival of monsoon, if irrigation facilities are available.
- If staggered sowing is unavoidable as in peri-urban baby corn and sweet corn cultivation, spraying with 5% NSKE or azadirachtin 1500 ppm @ 5ml/l at weekly interval or release of *Trichogramma pretiosum* @ 16,000 or *Telenomus remus* @ 4,000 adults per acre at weekly intervals, starting within a week of germination till harvest.
- Installation of FAW pheromone traps @ 5/acre on or before germination of the crop to monitor pest arrival and population build-up. For mass trapping of male moths, 15 traps/ acre is recommended to keep population build-up under control.
- Erection of bird perches @ 10/acre at sowing.
- Weekly scouting and adoption of symptom based control measures on action thresholds to be done.
- During scouting, hand picking and destruction of egg masses and larvae by crushing or immersing in kerosene water is recommended.

6. Frontline Extension Initiatives on FAW in Collaboration with Researchers

On-farm trial (OFT) was formulated by the ICAR-Agricultural Technology Application Research Institute (ATARI), Hyderabad in consultation with ICAR research institutes (ICAR-IIMR, Ludhiana and ICAR-NBAIR, Bangalore) and State Agricultural Universities, *viz*., Tamil Nadu Agricultural Universtiy, Coimbatore; Acharya NG Ranga Agricultural University, Guntur and Professor Jayashankar Telangana State Agricultural University, Telangana. Interventions incorporated in IPM and bio-intensive IPM (BIPM) modules were implemented against FAW on maize by Krishi Vigyan Kendras (KVKs) in 19 districts across the states of Andhra Pradesh, Telangana and Tamil Nadu. The IPM options comprised of cultural practices, installation of sex pheromone traps for monitoring of adults, scouting, collection and destruction of egg masses, foliar sprays of neem oil, microbial biopesticides, *viz.,* entomofungal pathogen (*Metarhizium*), *Bacillus thuringiensis* (*Bt*), entomopathogenic nematode (EPN) and need based insecticidal sprays based on economic thresholds varying with crop growth stages. Among the biological options in IPM and BIPM blocks, plots with *Metarhizium anisopliae* and EPN application treatments gave higher yield. Scouting and removal of egg masses followed by application of neem oil, EPN, *Metarhizium* and insecticidal applications in leaf whorls were the most effective in managing the pest. Extensive efforts of KVK extension scientists in close coordination with researchers helped in building the capacity of extension officials to understand, interact and educate farmers on monitoring and management of this invasive pest on maize.

7. Collaborations

i. ICAR-IIMR in collaboration with ICAR-NBAIR developed and evaluated biocontrol technologies in maize. ICAR-IIMR in collaboration with ICAR-NCIPM to validating and deploying the IPM technologies.

ii. Constantly, ICAR-IIMR in collaboration with private partners to evaluate green molecules and development for FAW forecasting model.

iii. A contract research proposal has been formulated with ATGC, Hyderabad on "Mating Disruption technique for sustainable management of fall armyworm".

iv. ICAR-NBAIR is in collaboration with CABI to develop, validate, promote and deploy proven, sustainable technologies against FAW as an IPM package.

v. ICAR-IIMR is in constant touch with international organizations, specifically CIMMYT for the experiences, germplasm exchange etc.

vi. A project proposal on FAW titled "Development of sustainable management tools for the invasive pest, Fall Armyworm *Spodoptera frugiperda* (J. E. Smith) in maize" has been formulated by ICAR-IIMR in collaboration with ICAR-NBAIR, ICAR-IARI, NIPGR and sanctioned by ICAR-NASF.

8. Recommendations

FAW poses major challenge to the maize farming community and resulting as a new threat to the food and nutritional security. Implementation of multidisciplinary and multi-institutional strategies including extensive awareness creation is essential for improving the income of small holder maize farmers. The emphasis on pest surveillance, development of high yielding climate resilient hybrids with inbuilt resistance to insect pests with special reference to FAW should be done. Improved crop nutrition, biocontrol agents, agro-ecological approaches such as diversifying intercrops and trap crops should be integrated in mitigating the FAW damage as they are eco-friendly, target specific and improve resilience in a sustainable way. Also, prediction of possible migratory pathways of invasive insect pests helps in raising awareness, monitoring for early detection and formulation of appropriate IPM strategies. ICT tools play a very important role in forecasting pest incidence and spread, which has not that extensively deployed in FAW management in India. Public-private-partnership can be proved very effective in managing FAW. Budgetary support in research and development is utmost important for the management of this transboundary pest in a sustainable way.

9. Conclusions

Since the pest was alien in Indian condition, the detection and timely control measures were of foremost importance. The principal maize producing region of the country, *i.e.* Peninsular, Central and Eastern India has favourable temperature and humidity regime almost throughout the year. This always put a challenge to remain continuously vigilant not to allow the population built up in the region so that the insect does not migrate to wider areas. Insecticidal control of FAW is though an option, resistance built up is a matter of major concern. Hence, judicious application of pesticides along with other IPM strategies is very much essential. However, all control measures add up to the cost of cultivation that needs to be duly compensated with appropriate price support mechanism. Like grain maize, sweet corn and baby corn are also affected by FAW. Since mostly these two commodities are consumed raw as vegetable, pesticide residue is a matter of major concern. Appropriate training of farmers and extension agents in this regard is very much essential. It may be noted that several biopesticides has showed potential at laboratory or small-scale trials but their affectivity at large scale deployment, mass production, packaging and transport needs to be standardized before bringing these tools for large-scale control of FAW. Maize has a very good regeneration ability after FAW attack with favourable growth conditions like rain or irrigation and fertilizer management. Hence, panic application of pesticides need to be avoided, unless really needed.

Presently, maize growing farmers are fully aware of the FAW incidence and applying specific interventions. Intensive studies, rapid and coordinated action and inter-institutional collaborations have helped to contain the damage by the pest. Our experience in trying to tackle this notorious pest indicates that information sharing through various platforms and adoption of control measures at community level starting right from the time of sowing played a vital role in managing FAW. In the present scenario, India is well experienced with the tailored fit technologies with customization to suit local agro-ecologies and effectively dealing the transboundary pest, which in turn benefit immensely to the resource constraint small holders.

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Table 1. Host range of Fall armyworm in India

S.No	Family	Scientific Name	Common Name	References
1	Poaceae	*Zea mays* L.	Maize	Sharanabasappa et al.(2018a) Ganiger et al.(2018) and Shylesha et al.(2018)
2	Poaceae	*Zea mays* L.	Fodder Maize	Maruthadurai and Ramesh (2020)
3	Poaceae	*Sorghum bicolor* L.	Sorghum	Sharanabasappa et al.(2018b), Jaba et al. (2019), Venkateswarlu et al.(2018) and ICAR- IIMR (2019)
4	Poaceae	*Eleusine coracana* (L.) Gaertn	Finger millet	ICAR- IIMR (2019), Jaba et al. (2019) and Venkateswarlu et al. (2018)
5	Poaceae	*Pennisetum glaucum* (L.) R. Br.	Pearl millet	ICAR- IIMR (2019), Jaba et al. (2019) and Venkateswarlu et al.(2018)
6	Poaceae	*Echinochloa frumentacea* Link	Barnyard milltet	Roopika et al.(2020)
7	Poaceae	*Saccharum officinarum* L.	Sugarcane	Srikanth et al.(2018), Chormule et al. (2019) and Matti and Patil (2019)
8	Poaceae	*Brachiaria mutica* (Forssk)	Paragrass	Maruthadurai and Ramesh (2020)
9	Poaceae	*Megathyrsus maximus* (Jacq)	Guinea grass	Maruthadurai and Ramesh (2020)
10	Amarant haceae	*Amaranthus viridis* L.	Green Amaranthus	Maruthadurai and Ramesh (2020)

Source: Sharanabasappa et al. (2021)

Table 2. List of natural enemies recorded *on Spodoptera frugiperda* in the maize fields in India

S.No	Scientific Name	Order: Family	Nature of natural enemy	References
1	*Trichogramma* sp.	Hymenoptera: Trichogrammatidae	Egg parasitoid	Shylesha et al.(2018), Navik et al.(2019) and Sharanabasappa et al.(2020)
2	*Telenomus remus* Nixon	Hymenoptera: Platygastridae	Egg parasitoid	Shylesha et al.(2018), ICAR-NBAIR(2019) and Patel et al. (2020)
3	*Campoletis chlorideae* Uchida	Hymenoptera: Ichneumonidae	Endo-larval parasitoid	Shylesha et al. (2018)
4	*Coccygidium melleum*	Hymenoptera: Braconidae	Endo-larval parasitoid	Sharanabasappa et al.(2019)
5	*Coccygidium luteum*	Hymenoptera: Braconidae	Endo-larval parasitoid	Kannidi et al.(2020)
6	*Coccygidium transcaspicum* (Kokujev)	Hymenoptera: Braconidae	Endo-larval parasitoid	Gupta et al. (2020a)
7	*Chelonus formosanus* Sonan	Hymenoptera: Braconidae	Egg-larval parasitoid	Gupta et al. (2020b)
8	*Eriborus Sp.*	Hymenoptera: Ichneumonidae	Endo-larval parasitoid	Sharanabasappa et al.(2019)
9	*Exorista sorbillans* (Wiedemann)	Diptera: Tachnidae	Endo-larval parasitoid	Sharanabasappa et al.(2019), Patel et al. (2020)
10	*Odentepyris sp.*	Hymenoptera: Bethylidae	Larval parasitoid	Sharanabasappa et al.(2019)
11	*Cotesia ruficrus* (Haliday)	Hymenoptera: Ichneumonidae	Larval-pupal parasitoid	Gupta et al. (2019)
12	*Forficula sp.*	Dermaptera: Forficulidae	Predator	Shylesha et al.(2018)
13	*Harmonia octomaculata* (Fabricius)	Coleoptera: Coccinellidae	Predator	Sharanabasappa et al.(2019)

S.No	Scientific Name	Order: Family	Nature of natural enemy	References
14	*Coccinella transversalis* Fabricius	Coleoptera: Coccinellidae	Predator	Sharanabasappa et al.(2019)
15	*Eocanthecona furcellata* Wolff.	Hemiptera: Pentatomidae	Predator	Shylesha and Sravika (2018) and Sharanabasappa et al. (2020)
16	*Andrallus spinidens* (Fabr.)	Hemiptera: Pentatomidae	Predator	Shylesha and Sravika (2018) and Sharanabasappa et al. (2020)
17	*Spodoptera frugiperda* Nucleopolyhedro virus	Baculoviridae	Entomopathogen	ICAR-NBAIR (2019) and Raghunandan et al. (2019)
18	*Metarhizium rileyi* (Farlow) Samson	Ascomycota: Claviceptaceae	Entomopathogen	ICAR-NBAIR (2019)
19	*Bacillus thuringiensis* Berliner	Bacillales: Bacillaceae	Entomopathogen	ICAR-NBAIR (2019)
20	*Beauveria bassiana* (Balsamo)	Hypocreales: Cordycipitaceae	Entomopathogen	ICAR-NBAIR (2019)
21	*Beauveria felina* (DC.) J.W Carmich.	Hypocreales: Cordycipitaceae	Entomopathogen	Mohan et al. (2020)
22	*Heterorhabditis indica* Poinar, Karunakar and David	Rhabditida: Heterorhabditidae	Entomopathogen ic nematode	ICAR-NBAIR (2019)

Source: Sharanabasappa et al. (2021)

Chapter 6

Fall Armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith) - the status, challenges, and potential risks in Maldives

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1. Introduction

Discovered in 2016 in central Africa, Fall Armyworm (FAW) is now reported in many Asian countries including India, Bangladesh, Sri Lanka, Thailand, Myanmar, China, Indonesia, and the Philippines (Lamsal, Sibi, & Yada 2020). According to FAO, Global Action Framework, 2020, this pest has the potential to destabilize forestry, agriculture, and biodiversity sector on a global scale.

Maldives has had a very defined agriculture industry. In the early days, production was limited to crops that are well adjusted to the island ecosystem. Various tropical fruits and vegetables were cultivated across the country. The crop choices were directed primarily to manage the nutritional needs of the household. The harvest provided much needed carbohydrates and vitamins which were combined with fish and fish products as the major source of protein.

Intensification of agriculture sector in the islands coincided with the advent of tourism development activities. New germplasm and species were introduced along with consignments of items brought in to cater for the resorts. Subsequently, hybrid crops were being substituted by growers. This in turn, necessitated the need to use external fertilizers in addition to the plant-derived compost sourced from the island ecosystem. Consequently, many new pests and diseases were surfacing in major growing areas. The novelty of these introduced pests required the use of abrupt control measures. Hence, various chemical pesticides became the mainstream norm. By the early 1990's, many of the persistent pests and diseases such as whitefly (*Bemisa spp)*, mealybugs (*Pseudococcidae spp)*, Citrus canker (*Xanthomonas citri*), Gypsy month (*Euproctis fraterna*), and common Army worm (*Spodoptera spp*) had already been established.

2. Country status

As of 2020, FAW has spread to more than 66 countries, including 19 Asian countries (Lamsal, Sibi, & Yada 2020). As per incident reports, surveillance information and field observations, there is no evidence to suggest the presence of FAW in Maldives, at the moment. According to Lamsal, Sibi, & Yada (2020), many of the major grain crops are included among the host range of FAW. In Maldives, grain production was carried out in many parts of the country in the years prior to 1980's. These crops were mainly, maiz (*Zea mays*), Finger Millet (*Eleusine coracana*), Sorghum (*Sorghum spp*) and Barley (*Hordeum vulgare*). These latter crops are now almost non-existent in both homegardens and commercial production systems. However, maize is grown for home consumption in some of the northern islands. The production area is limited to homegardens and small patches in a mixed cropped setting. In addition, Sugarcane (*Saccharum officinarum*) is also grown in homegarden settings for home consumption.

Furthermore, other major host crops of FAW, such as cotton and wheat are also not cultivated. However, some ornamental varieties of cotton could be found in homegardens. In contrast, some crops that are found in the horticultural sector such as cabbage, capsicum and other field greens could be placed high on the potential susceptible crops list for FAW.

3. The Role of Plant Protection Section at MoFMRA

Ministry of fisheries, Marine Resources and Agriculture (MoFMRA) is responsible for the statutory aspects of imports and exports of live plants, animals and related commodities. The Plant Protection and Quarantine Services of MoFMRA is responsible for preparation of operational guidelines/ procedures/instruction to ensure nation-wide adherence to phytosanitary sanitary standards. It is also responsible for managing all national plant health related issues. This section of MoFMRA is aimed to function as the National Plant Protection Organization (NPPO) to represent Maldives under the FAO regulations. One of the main day-to-day tasks of the section is to issue foreign trade permits for plants, plant parts, depending on national regulations and disease status of the exporting country.

This is a newly formed section of the ministry which is still under development. One of the main objectives of plant protection service is to prevent the entry of exotic pests, plant and animal diseases while facilitating international trade in plants, plant parts, live animals, and other related products. This section is also responsible for promotion of Good Agriculture Practices (GAP) for whole-farm and individual crop basis.

4. The role of Plant and Animal Quarantine Unit (PAQU)

The Plant and Animal Quarantine Unit (PAQU) was established in 2007 with the broad aim of enforcing national and international standards regarding plants protection and animal health. Before the establishment of PAQU, Maldives Customs Service has had the initiative, but mechanisms were not succinct and plant protection objectives were not prioritized. PAQU is operated within the Plant Protection and Quarantine Section, under MoFMRA. PAQU has the infrastructure to hold plants and animals in isolation with no contact with native biodiversity to reduce the likelihood for entry of a new pest or disease. PAQU has the legal mandate and administrative authority for control and supervision of importation and exportation of plant, animal, and related commodities. The regulations put forward by World Animal Health organization (OIE) and International Plant Protection Convention (IPPC) are adhered as basis for actions carried out at quarantine facility. PAQU is fully staffed with; 1 (one) Senior Quarantine Officer and 5 (five) Quarantine Officers and 3 (three) Support staff.

PAQU staff - Quarantine Officers, carry out physical inspection of imported consignments of plant, plant parts and animal on collaboration with other border control authorities. They also maintain a database of importers, imported items and changes to international trade relating to regulated and quarantined pests etc. PAQU work with relevant institutions to facilitate boarder Inspection and to establish Quarantine Check Posts at relevant ports. Currently, the border network includes 7 airports and 3 seaports which are not adequately equipped to regulate plant and animal products. PAQU has been directed to monitor and inspect plant consignments coming from SAARC region as part of the prevention strategy for Fall Army Worm management.

5. The pest surveillance, data collection and reporting programs

Plant protection section of MoFMRA has established a system for surveillance of pests and diseases. Through this system, wherever necessary, plant and animal disease situation of the exporting country is considered, and risk assessments are carried out. As part of the surveillance programs, the ministry organizes visits to various key islands on annual basis. During these trips, information is collected on new pests and diseases and other key issues relating to plants protection. However, this process has been halted since late 2019, due to Covid-19. Farmers and growers are encouraged to keep close relationship with NPPO and agriculture extensions officers to identify issues in a timely manner. In addition to the pest surveillance programs, the ministry also monitors major pathways of plant movement between islands. In this respect, permits must be obtained by all parties, for any domestic activities that involve plant movement between islands. Permits are issued based on the potential risk of a regulated pest dispersal. This work is carried out in collaboration with Environmental Protection Agency (EPA). Currently, the main pests of note are Coconut Hispid Beetle (*Brontispa longissima*), Papaya Ring Spot Virus, Taro Leaf Blight and Chili leaf Curl Virus. These pests and diseases have been noted to cause significant economic loss to the farmers and tourist resorts.

Additionally, all plant nursery activities are being registered with MoFMRA. The guidelines for registration include regulation and monitoring processes to cater for; pest management, agrochemical use and plant movement to and from nursery ventures.

6. Risk lowering factors

The geographically isolated nature of Maldivian islands would likely be an obstacle for natural transfer of the pest. Also, upon a potential introduction, it would require less effort to contain the pest to the introduced area or island. Apart from that, the fewer number of host crops in the production system would also avert a potential outbreak, reducing a resulting economic damage. As stated earlier, many of the major prominent host crops of FAW including maize, sugarcane and grain crops are not cultivated for commercial production. This would limit the likely proliferation of FAW in a single area. Also, the mixed cropping setting described earlier would reduce the potential damage from FAW if introduced (Rwomuhana, Bateman & Beal et al 2018).

Additionally, many turfgrasses such as Bermudagrass, have also been identified as the hosts of FAW (Day, Abrahams, & Beale et al, 2017). Maldives does not have pasture industry and native grasses are mostly used for landscaping in the resort sector. Artificial turfs are maintained in the sports industry as well.

Additionally, the very nature of farms, its size and location across the country would also act as a likely hindrance for a rapid dispersal of insect pests. The average farm size is in the range of 5000 to 10000 square feet. And for homegardens it would be in the range of 2500 to 5000 square feet. Hence, in the current setting, FAW could be managed at threshold level given that the process is carefully executed.

MoFMRA has been promoting Good Agriculture Practices (GAP) scheme across the atolls. Few notable large-scale farmers have already adopted the scheme. This will strengthen the pest management capacity at farm level. The scheme is also supported by newly enacted Pesticide Control Regulation 2019. The regulation demands farmers and growers to carry out certain activities in relation to pesticide application and farm record keeping.

In addition, under the new Strategic Action Plan of 2021, Integrated Pest Management is to be established in few selected islands at island level. Hence, this activity will enable a combined effort from the selected island communities and facilitate the chance to demonstrate the importance of IPM and collective effort in managing pests in a locality.

7. Challenges and risk enabling factors

The insect can complete several generations in a year and likely become endemic to the Indian subcontinent. The life cycle of FAW in Latin America is completed in about 30 days (at a daily temperature of approximately 28°C) (FAO, 2017). These environmental parameters are similar to the average climatic conditions of Maldives.

It has been identified that, FAW feed on over 80 different crop species, making it one of the most polyphagous and damaging crop pests. Maldives has a predominant horticultural production system. As per the research FAW has been seen in many vegetable crops showing affects at varying levels (Rwomuhana, Bateman & Beal et al 2018).

Apart from that, most Maldivian farmers are smallholders. Even the large-scale farms are not in same scale when compared to other South-asian countries. Hence, a large scale FAW infestation incident would make farmers vulnerable and put pressure on sourcing more inputs (Hruska, 2019).

Another major problem associated with FAW infestation is the increased use of hazardous pesticides, as these represent an immediately available solution to farmers but, at the same time, are harmful to humans, animals and environment (FAO, 2020). The Maldives has few established input suppliers who have been notably successful at advocating on behalf of synthetic pesticides. The newly formed Pesticide Advisory Committee under the Pesticide Control Regulation 2019 is not up to speed with the current changes in relation to FAW.

Additionally, Maldives is not included in the FAO global management Framework. This is partially because of lower rate of poverty, hunger rates, lower number of famers etc. The lack of participation in these initiatives is likely to lower the level of response and resources deployed in case of a major infestation.

Moreover, MoFMRA records show increasing trend of plant imports since the onset of Covid-19. Encouraged by the new lifestyle set as a response to Covid-19, majority of the community have taken to plant cultivation for ornamental and food purposes. This trend has put immense pressure on MoFMRA and border control authorities in terms monitoring of imported consignments in an effective and timely manner. This trend has lead to increased diversity of non-native plants and increased use of various agricultural inputs.

This change has necessitated the need to have strict and enforceable protocols for managing Quarantine Pests. As things stand, the procedures are not comprehensive and collaboration between institutions are lacking. Additionally, The Plant Protection Act of 2011 is not regulated to this day. This has become a hindrance to the overall national effort to effectively manage pests and diseases.

Furthermore, a successful pest management for Maldives relies heavily on the capacity of individual islands. The government has been trying to promote local governance to improve the livelihoods of people and increase local participation and efficiency of programs carried out. In this respect, all island level pest management programs are also planned to be run through direct involvement of island councils. Due to this, MoFRMAs' capacity in enforcing timely activities has been hindered. Moreover, the councils are not equipped with resources required to effectively manage pests in a timely manner.

8. Recommendations

It is also important to promote uniform, country-wide procedures to imports of all live plants and plant parts. Hence, regional quarantine facilities should be established in all major ports to reduce economic loss and potential introduction of a notorious pest.

Decision-makers must be aware of potential threats from emerging pests and need to have access to information and advice regarding effective and sustainable policies and programs. In this respect it is important to use political initiative to formulate 'Time-critical measures' to support early warning and monitoring of a potential pest entry. Additionally, policies need to be formulated for managing 'Transboundary pests' which is currently lacking in the existing legislations.

The fact that FAW quickly develops resistance to many active substances put Asia on an unsustainable and dangerous "pesticide treadmill" (Lamsal, Sibi, & Yada 2020). Hence, a full range of science-based solutions must be tested and evaluated against efficacy and cost-benefit, to support producers in adopting and scaling up different options (FAO, 2020). In line with this the national surveillance, research, and monitoring procedures for both regulated and quarantine pests must be strengthened. This should include surveillance activities at entry points and in on-going production activities in the islands. To expedite that, mechanisms to communicate FAW and other potential pests with domestic collaboration agencies such as the Maldives Customs Services and Local Government Authority is to be established and streamlined.

Additionally, agricultural land-use guidelines are to be improved to regulate and promote non-pesticide options for pest prevention among islanders to reduce potential negative responses of FAW introduction. These activities could be tied up with land-use plan development work at island councils.

Conjointly, awareness among public on existing regulations including the Plant Protection Act and Pesticide Control Regulations are to be actively promoted on various platforms. Prominent of these platforms include the existing national agricultural advisory programs run by MoFMRA and training programs carried on collaboration with various public media outlets. The awareness programs could put more focus on biopesticide promotion, IPM, GAP and safe methods on plant import and export procedures.

IPM packages need to be developed to include specific Biocontrol options based on proven research. Biological control using egg parasitoids particularly from the genus *Trichogramma spp* and *Telenomus remus* as part of the IPM approach could be a rewarding option for island ecosystem as a long-term measure to control FAW (Tefera, Muluken & Malik et al, 2019). additionally, both GAP and IPM schemes should focus on promoting minimum tillage, inter cropping, thinning, and clean cultivation methods as a general approach to control major pests.

Moreover, It is important to establish pathways with SAARC member countries to exchange germplasm and research opportunities. In-line with this, capacity building programs are to be carried out to plant protection officials at the ministry and in the private sector. These programs need to be extended to local island councils in the effort to allocate skilled focal points to manage FAW and the likely similar pest and disease incidents at island level.

Moreover, the technical and infrastructure capacity of NPPO within MoFMRA needs improving. This is mainly to upgrade and expand surveillance, monitoring, information processing and information communication programs being carried out by NPPO on behalf of MoFMRA in both technical and public capacity. In support of this activity, the multipurpose laboratory at PAQU could be improved to better diagnose issues at the border as part of the quarantine and inspection procedures.

Moreover, connections need to be strengthened with SAARC member countries and specialist organizations for obtaining Natural Enemies and biocontrol agents to increase available options and reduce detrimental methods to control possible impact from FAW.

9. Conclusion

FAW having already colonized many nearby countries poses a huge risk to Maldives. The introduction of FAW is to be anticipated and prepared for. Even though FAW has not been reported its impact to the cropping areas of Asia and other countries can affect Maldives as it depends on foreign produce for its major food requirement. The arrival of each new disease is likely to consume lot of resources and would put a toll on the forestry, tourism and agriculture sector. The current procedures in place to prevent the entry and potential spread of FAW may not be sufficient. Measures need to be taken to improve the overall all legislation, human resource capacity, infrastructure, and collaborations of MoFMRA and the private sector towards plant protection and prevention. In this respect the regional collaboration and support is crucial

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Chapter 7

Fall Armyworm (*Spodoptera frugiperda*) in Nepal: Current Status, Challenges and Experiences

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1. Introduction

Spread of invasive pests and diseases, which are often considered one of the largest constrain in the production of agricultural crops has impact negatively in global agriculture. Some of these pests have caused significant damage in the production of the commodities which has caused difficulty in the food security. Maize is an important cereal crop and staple food for many people around the world. The Fall Armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) can affect all stages of development in maize and is difficult to control (USAID, 2017). According to Montezano (2018) FAW larvae can reportedly feed 353 different plant species but in Nepal this pest is a major threat especially for maize crop. Maize (the most preferable host of FAW) is the second largest crop cultivated in the country in terms of area and quantity of production with the total area of cultivation of 954158 hectare and total crop production of 2555847 metric tons (AICC, 2019/20).

Maize crop in Nepal is mainly cultivated as summer crop but with the increased irrigation facilities in river basins and plain areas, the year-round cultivation of maize crop is also increasing (Poudyal et al., 2001). For FAW to be established, the temperature during pre-monsoon, monsoon and post monsoon is highly favorable. According to CABI (2019), the climatic conditions in Nepal are suitable for the establishment of FAW populations, which could potentially cause upto 100 percent crop loss. Thus, the infestation of this pest possesses very high risk of food and seed insecurity especially in the mid hill region of Nepal. FAW has been reported in maize and sorghum field so far in Nepal. The yield losses from FAW in Africa have been reported ranging from 21 to 53% in maize (Prasanna et al., 2018). FAW has affected maize crop in all seasons. The average area affected by FAW is estimated to be 371835 ha (38.97%) and estimated loss caused by FAW is about 16.51 % in the affected area (PQPMC, 2021 unpublished compilation).

2. Declaration of FAW Invasion in Nepal

National Plant Protection Organization (NPPO) Nepal had alert on invasion of FAW since the entry of this pest in Karnataka of India in 2018. Continued surveillance and field visits were carried out to detect the potential invasion of this pest especially in the maize growing areas of Nepal. The insect had been recorded for the first time in Nepal from Nawalpur district (N 27°42′16.67″ E 084°22′50.61″) on 9th May 2019 (Bajracharya et al., 2019) and after multiple surveillance field visits and the investigation of many suspected samples, NPPO of Government of Nepal authentically declared the introduction of fall armyworm in Nepal on 12 August 2019 (PQPMC, 2019).

3. Occurrence and Distribution of FAW

Soon after declaration of its invasion in Nepal, governmental and non-governmental organizations have been monitoring FAW occurrence in different districts of the country. FAW has been reported from from sixty-four districts of Nepal from all provinces (PQPMC, 2021 unpublished compilation) ranging from mid hills to terai districts until February 2021 (Fig. 1).

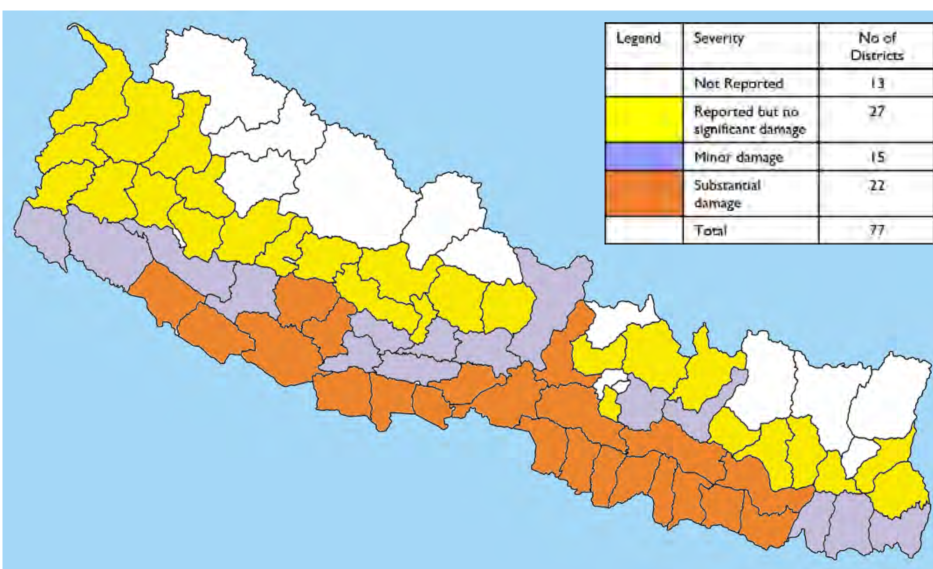

Fig. 1. Occurrence and distribution of FAW in Nepal, February 2021.

4. Efforts and Experiences in FAW Management After Invasion

Extension and Management

- A network of central level technical and steering committee, provincial and district level FAW management task force formed and activated for awareness, orientation and overall management of FAW.
- Many awareness programs and field level trainings are organized through governmental and non-governmental organizations.
- Protocol for FAW Surveillance, Integrated Pest Management (IPM) and Action plan prepared and endorsed in Technical Team and NPPO Meeting. Many information materials were prepared and distributed, and mass communication media and social network was used to disseminate the information. Pest Management Decision Guide (PMDG) and Photo Guide (identification, life cycle, damage system) of FAW prepared and distributed among technicians.
- Training of Trainers (TOT) on FAW identification and management to the provincial level technicians and Private sector engagement training on FAW identification and management (Pesticide importers and distributors) at central level were organized.

5. Research Activities

Many research activities have been initiated and are ongoing in Nepal Agriculture Research Council and its research centres, most of them are still ongoing.

- Maintaining the culture of *Trichogramma* and *Telenomus.*
- Other research activities:

  (1) Monitoring of FAW through pheromone lures and black light trap,

  (2) Study of seasonal infestation of FAW,

  (3) Evaluation of safe chemical insecticides available in market against FAW,

  (4) Screening of maize genotypes against FAW,
- National Maize Research Program (NMRP)/NARC and NSAF/CIMMYT have been testing the trials to evaluate the efficacy of push-pull cropping system which is considered one among the best climate-smart technologies. Napier grass (*Pennisetum purpureum*) as pull and silver leaf desmodium legume (*Desmodium uncinatum*) as push crop have been included in the study.
- Efforts are being made to collect and identify the local races of bio-control agents effective against FAW. *Trichogramma* and *Telenemous* have been

identified and cultures have been maintained in the Entomology lab of NARC and National Maize Research Program.

- Study on biology of FAW in the laboratory conditions and efficacy of different pesticides and indigenous methods for the management of FAW are also going on.

6. Integrated Options Adopted for FAW Management

For immediate response to FAW management the management options were prepared and suggested to the technicians and farmers (PQPMC, 2019) as follows:

- Seed treatment by Imidacloprid 48% FS @ 4 ml per kg of seed.
- Selection of variety of maize in which husk fully covers the cob.
- Adjustment in plantation dates of to escape the peak migration of FAW adults.
- Optimum fertilizer application or manure to boost the crop growth vigor.
- Deep ploughing of the maize field before planting to expose and kill pupal life stage of FAW.
- Maintaining plant diversity on farms.
- Use of push-pull technology (Desmodium grass for push and Napier grass for pull but need to be validated).
- Destroy the eggs, larvae and pupae in the crop residues after harvest by deep burying the plant residues in soil.
- Practice of crop rotation and intercropping.
- Mechanical crushing of egg masses and young larvae.
- Use of ash, sand, sawdust or dirt into whorls which may desiccate young larvae.
- Use of local botanicals (Neem, hot pepper, local plants).
- Conservation of naturally occurring biological control agents of parasitoids, predators and entomopathogens.
- Use of introduced bio-control agents like *Trichogramma chilonis* @100000 per ha.
- Chemical pesticides.
- Use of Azadirachtin 1500 ppm @ 5 ml per liter of water or BT @ 2 gm/liter of water against early instar larvae.
- Application of Spinetoram 11.7 SC @ 0.5 ml or Spinosad 45%SC @ 0.3 ml or Chlorantraniliprole 18.5% SC @ 0.4 gram or Emamectin benzoate 5% SG @ 0.4

gram or Thiomethoxam 12.6% + Lyambda Cyahalothrin 9.5% ZC @ 0.5 ml per liter of water.

7. Challenges

There are various challenges faced in the management of FAW in Nepal. Some of the major challenges for the management of FAW in Nepal have been mentioned below:

- Current lockdown of the country due to COVID-19 pandemic has disrupted the implementation of the different planned activities (training, workshop, set up of the recommended packages trials, and collaborating activities on time.
- Low level of research and technology known (zero local knowledge as it is new pest, botanicals will be cheaper but not tested and recommended yet, biologicals not yet developed but initiated for the mass rearing of the *Trichogramma chilonis* and *Telenomous* by NARC, the other non-chemical approach not tested in country, poor access to recommended pesticides and costly pesticides, under capacity of frontline workers etc, less manpower and resources in research. Unavailability of true type of FAW lure to monitor (many lures are found less efficacy which catches the mixed types of moths into the trap) effectively, late reporting by farmers, less number and less capacitated front-line technicians, low capacity on system development need to be addressed.

8. Recommendations

As this is a new pest, there are several challenges faced during this period. Some of the recommendations are listed hereunder for the effective management of this pest.

- Capacity enhancement through trainings and orientation to farmers, technicians and input suppliers.
- Increasing resources on research and extension.
- More co-ordination and networking with international level stakeholders.
- Monitoring and early warning system development.
- Botanicals and biological pest management solutions.
- Reporting system functionalizing and co-ordination mechanism strengthened to three tiers of government.
- Co-ordination mechanism further strengthened among national and international level organizations.

- Use of digital technology in current lock down through Virtual meetings and the utilization of social media platforms can be effective in the current lockdown to communicate important information regarding FAW management and IPM practices and technologies. Bulk SMS messages to the extensions practitioners Community Business Facilitators (CBFs), Plant doctors, and MPC/CCs members, not only provide timely alerts but also provide valuable IPM recommendations for FAW management.

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Chapter 8

Status, challenges and experiences of Fall Armyworm (*Spodoptera frugiperda*) in Pakistan

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1. Introduction

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) is an emerging and most destructive pest species. It is native to Americas. This insect was known as a super pest of the UN Food and Agriculture Organization Global Alert (FAO, 2017).The pest is considered chronic (Flanders *et al.,* 2017) which means that it reoccurs nearly every season in infested areas.

The genus *Spodoptera* consists of a number of species that are important crop pests including *S. littoralis* (Boisduval) (the Egyptian cotton leafworm), *S. exempta* (Walker) (the African armyworm), *S. litura* (Fabricius) (the tobacco caterpillar), *S. exigua* (Hübner) (the beet armyworm), *Spodoptera ornithogalli* (Guenée) (Yellow striped armyworm), and *S. frugiperda* (J.E. Smith) (the fall armyworm).

Two morphologically identical strains of *S. frugiperda* are recognised, commonly referred to as the corn strain and the rice strain, due to host preferences. There is a high level of genetic differentiation between the strains (Pashley, 1986; Kergoat *et al*., 2012; Juarez *et al*., 2014) as well as differences in diurnal mating pattern (Hanniger *et al*., 2017) and differences in female sex pheromones (Lima and McNeil, 2009). Dres and Mallet (2002) considered the rice- and corn-associated S. *frugiperda* as separate species. Prowell *et al*., (2009) suggested that they were recently evolved species that are not completely reproductively isolated. Other authors suggest that *S. frugiperda* is still in the process of speciation (e.g. Groot *et al*., 2008; Juarez *et al*., 2014).

It has a preference for wild and cultivated grasses, maize, rice, sorghum, millet and sugarcane (Poaceae). Other hosts from 27 families include Allium (Liliaceae), Brassica spp. (Brassicaceae), Capsicum and other Solanaceae including aubergines, potatoes and tomatoes, Cucumis (Cucurbitaceae), Gossypium (Malvaceae), Phaseolus (Fabaceae) and Ipomoea (Convolvulaceae) as well as various ornamental plants (chrysanthemums, carnations and Pelargonium) (Smith *et al*., 1997; CABI, 2017). In laboratory host preference studies examining larval feeding choices, maize and wheat were preferred above soybean and cotton (Silva *et al*., 2017).

The FAW completes its life cycle in about 30 days during the summer. But, the duration can be extended to 60 days in the spring and autumn, and 80 to 90 days during the winter. There are no reports on the ability of FAW to diapause. FAW has 6 larval instars per generation and can have multiple generations per year (Capinera, 2001). Adult FAW moths deposit a layer of egg masses on the leaves of host plants that will hatch within 2-3 days. FAW causes damage to crops mainly by larvae feeding on leaves of the plants.

Female moths of FAW prefer young corn plants that are 1 to 2 feet in height for ovipositon and the small caterpillars are found feeding on leaves of young corn plants. In whorl-stage plants, young larvae feed on the outer leaves and move into the whorl, subsequently damaging the emerging tassels. All larval stages can feed on the ear, with young larvae feeding on the silks and entering through the cob tip; older larvae generally enter through the husk (Nuessly and Webb, 2001).

S. frugiperda is considered the most important pest of maize in Brazil, estimated to cause more than US $400 million damage annually (IITA, 2016). The FAO estimates Brazil spends US $600 million annually controlling infestations of *S. frugiperda* (Wild, 2017). Following its introduction into Africa, *S. frugiperda* has been reported damaging maize (Goergen *et al*., 2016). It was reported to invade south East Asia in early 2018. FAW marked its presence in June 2018 in India (Sisodiya et al., 2018). Later by the end of 2018, it was reported from Bangladesh, Sri Lanka and Thailand and China (FAO, 2018).

2. Fall Armyworm in Pakistan

Director Plant Protection, Pakistan Agricultural Research council (PARC) collected some larval samples infesting spring maize in May, 2019 from Tando Jam Sindh and submitted for identification to National Insect Museum, National Agricultural Research Centre, Islamabad. The samples were studied and identified morphologically as *Spodoptera frugiperda.* The FAW presence in Pakistan was reported to Pakistan Agricultural Research Council on May 15, 2019. Naeemullah et. al. (2019) reported presence of fall armyworm in Sindh, Pakistan. Gilal et al. (2020) conducted a study in 15 corn growing areas of Sindh, Pakistan to determine the presence and damage status of FAW on fodder and grain corn along with sorghum and millet. The presence of FAW was confirmed from all corn growing districts of Sindh except Jacobabad, Larkana and Shikarpur districts of upper Sindh. More damage was recorded in fodder corn than in grain corn. The presence of FAW was also recorded from sorghum and millet. The 100% damage was recorded on fodder corn in Shaheed Benazirabad district. Khan et. al. (2020) reported presence of fall armyworm in maize fields from Faisalabad, Pakistan. Later in 2020, Department of Plant Protection, Government of Pakistan officially declared the presence of fall armyworm in Pakistan.

3. Crops Affected

Pakistan is an agricultural country and variety of crops is grown there. Cotton, wheat, paddy, sugarcane, sunflower along with fruits and vegetables occupy major cropping area in Pakistan. FAW has been reported to have broad host range with more than 350 plant species as alternate hosts. In Pakistan so far mainly fodder maize is reported being attacked by fall armyworm.

4. Management of Fall Armyworm in Pakistan

FAW has invaded Pakistan on limited area in recent past. Being signatory of International Plant Protection Convention (IPPC) Department of Plant Protection, Government of Pakistan has issued advisory to provincial agriculture departments for affected areas to curtail its attacks.

Provincial Agricultural Departments are providing information and control measures to farmers as per guidelines of DPP for management of FAW. At present farmers are using synthetic pesticides like Emamectin benzoate, Lufenuron, Carbosulfan, Chlorantraniliprole, and Spinetoram registered against other armyworm in Pakistan. Though these pesticides are effectively managing FAW populations, however indiscriminate use of these pesticides will not only effect production cost but will also effects environment adversely. They will kill natural enemies in the ecosystem and produce harmful effects on humans and livestock. This necessitates development of integrated pest management strategies of FAW. Research has been initiated by academia, provincial and national research organization for the development of holistic and integrated management strategies under local conditions.

5. Recommendations

FAW is an invasive alien species for Pakistan. There is need to undertake countrywide detail surveys for damage assessment and search natural enemies of FAW available in Pakistan. Once explored, these natural enemies should be reared and released to develop self-sustaining biological control system. Further research should be conducted to understand the biology of FAW in local environment and development of other control/management options.

Telenomus remus (Hymenoptera: Platygastridae) an egg parasitoid of FAW has been previously reported from Pakistan. Biological potential of this egg parasitoid should be explored. Efforts should be done to develop an augmentative biological control system based on this egg parasitoid. It should be cost effective and risk free to environment and human health.

CABI Bioscience has imported an egg/larval parasitoid *Eiphosoma laphygmae* Costa Lima (Hymenoptera: Ichneumonidae) from Switzerland. Laboratory culture has been successfully established under local condition. Host range testing is done in newly constructed quarantine laboratory.

Another larval parasitoid *Microplitis* sp. (Hymenoptera: Braconidae) has also been recorded parasitizing FAW larvae in Pakistan. It is still in identification and confirmation process. Efficacy and biological potential of this larval parasitoid should also be explored in bringing the FAW population under control.

Conclusion: FAW is invasive alien species for Pakistan. It has wide host range with more than 350 plant species as alternate hosts including wheat, paddy and sugarcane. Research and speedy efforts are required to develop IPM strategies under local conditions to curtail and restrict its spread and avoid total crop failure in Pakistan. Early we detect and assess, less we will be prone to damage.

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Chapter 9

Fall Armyworm: the status, challenges and experiences in Sri Lanka

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1. Introduction

Maize, (*Zea mays* L.), is considered as the second most important cereal crop grown in Sri Lanka next to rice in terms of extent cultivated, foreign exchange involved in imports and agro-industrial utilization (Hindagala, 1980). Maize is cultivated mainly in two cropping seasons of the year namely m*aha* (rainy season) under rainfed conditions and y*ala* (dry season) under irrigated conditions. The total extent of maize cultivation in Sri Lanka is about 93,324 ha and annual production was about 368,864 mt in 2020 (Crop Forecast, 2020). Maize is used directly as food, livestock feed and raw material for numerous industrial purposes (Chaudhry, 1983). Several pests have been recorded on maize cultivation in Sri Lanka. Of these pests, the maize stem borer (*Chilo partellus*) and the new alien invasive pest Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) are considered as the economically important pests causing substantial yield losses of maize in Sri Lanka.

Fall Armyworm (FAW) is a transboundary insect pest, native to tropical and subtropical regions of the Americas. In the absence of natural control or good management, FAW can cause significant yield losses to different crops including maize and more than 80 additional species of crops, including rice, sorghum, millet, sugarcane, vegetable crops and cotton (Andrews,1980). The occurrence of multiple generations, the ability to migrate, and the ability to feed on a wide range of host plants makes fall armyworm one of the most severe economic pests.

FAW was first detected outside of its native South America in 2016 in Central and Western Africa (Goergen *et al.*, 2016). It was reported in Karnataka state of India and Yemen in July 2018 as the first occurrence in Asia. Since then, the FAW has continued to spread to other countries in the Asian region and it has been reported for the first time in Sri Lanka in October 2018. By the end of 2018, FAW was spread to Bangladesh and Myanmar and in January 2019 in Thailand, Vietnam and China (FAO, 2018a, FAO, 2019). The incidence of this pest was first observed in Ampara and Anuradhapura districts in Sri Lanka and reported all over the country by January 2019 (Fig.1).

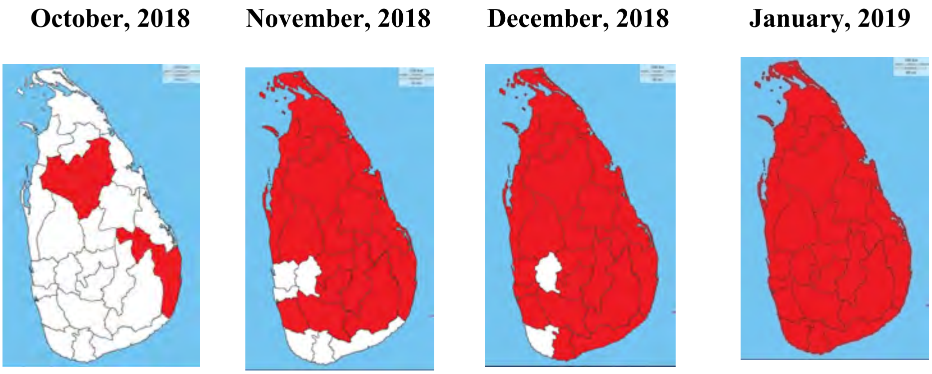

Fig. 1: Spread of Fall armyworm in Sri Lanka

FAW damages the maize crop both at vegetative and reproductive stages. Leaf damage is usually characterized by ragged feeding and moist sawdust-like frass appears near the funnel and upper leaves. Deep feeding in the leaf funnel may destroy the growing points and developing tassels. Caterpillars tend to enter the ear through the side and feed on developing kernels (FAO, 2017, FAO, 2018b and Prasanna *et al*. 2018) (Fig. 2).

Fig.2: Damaged maize plants at different stages

2. Crops affected by Fall Armyworm and extent of spread in Sri Lanka

FAW damage was first observed on maize cultivation in Sri Lanka. The total extent of maize cultivation was around 82,000 ha in rainy season (*Maha* 2018/19) and the infested area was 43,037 ha. The estimated yield loss due to FAW damage varied 10-25%. However, cultivated extent was low during dry (yala) season and very low infestation was reported (Table 1). The pest was found damaging on sugarcane in Sri Lanka.

Table 1: Cultivated extents of maize and infestation levels of FAW in Sri Lanka

Season	Total cultivated extent (ha)	Total infested extent (ha)	Estimated yield loss
Maha 2018/19	88154	43 576	10-25%
Yala 2019	6114	-	-
Maha 2019/20	79071	144	<5%
Yala 2020	13253	-	-
Maha 2020/21	101054	21600	

Source: Crop Forecast, Department of Agriculture, 2018,2019,2020

3. Management of Fall Armyworm through IPM and other practices

FAW infestation has short and long term impacts on agricultural production, food security and poultry industry. Hence, it effects the livelihood of thousands of value chain operators on various commodities in the country. Therefore, sustainable management is needed to mitigate the FAW damage. Detecting fall armyworm infestations before they cause economic damage is the key to their management. In other countries, several pest management options such as use of sex pheromones, botanicals, biopesticides, insecticides and push pull technologies have been adopted against FAW (Bateman *et al.*, 2018, Bhan *et al.*, 2013, Hailu *et al*., 2018, Hardke *et al*., 2011 and Midega *et al*., 2018).

As the pest is new to Sri Lanka, local information on its behavior, biology and management options were not available. Once Sri Lanka received the alerts on the presence of the pest in the neighboring country India through different sources, immediate steps were taken to make aware the people on identification of FAW via newspaper articles, leaflets, posters. The leaflet on management of FAW using insecticides and other management strategies was prepared based on the available literature and distributed across the Sri Lanka. As the first line of defense, several insecticides were tentatively recommended for the management of FAW. Further, several other management strategies such as correct time of planting, avoid staggered planting, deep ploughing and destroying inactive pupal stages from the soil, application of sand or ash to the growing point at the initial stage, application of recommended fertilizer to the field, the establishment of pheromone traps to attract male moths were recommended as immediate control strategies. After the establishment of crop regular monitoring and scouting is essential to ensure early detection of the pest.

Many activities were initiated by the Government of Sri Lanka with the collaboration of Food and Agriculture Organization of the United Nations to contribute to the protection of livelihoods and food security of the farming community of the FAW affected areas and developing capacities of main stake holders in awareness, surveillance, monitoring and integrated management of the FAW. This was initiated under the FAO funded project "Emergency response to enhance technical capacity for early warning, monitoring and management of FAW in Sri Lanka".

4. Strategies to control Fall Armyworm and research studies conducted

Host plant resistance studies

Twelve exotic hybrid varieties (PAC 339, PAC 999, PAC 984, PAC 139, PAC 293, PAC 022, Kafeer, Bell, HP 4311, Jet 999, CP 808), two local hybrid varieties (MI MZ HY 01, MI MZ HY 02) and two local open pollinated varieties (Ruwan and Badra) were evaluated under insecticide free conditions to identify varieties capable of resisting FAW damage. The highest FAW damage were recorded in all the tested varieties and hybrids at 6-8 weeks after sowing during both seasons. However, the severity of foliar damage was reduced later in all the tested varieties (Fig. 3 and Fig. 4). Severity index of cob damage was low in all the tested hybrids/varieties and there was no significant difference in cob damage among them (Table 2).

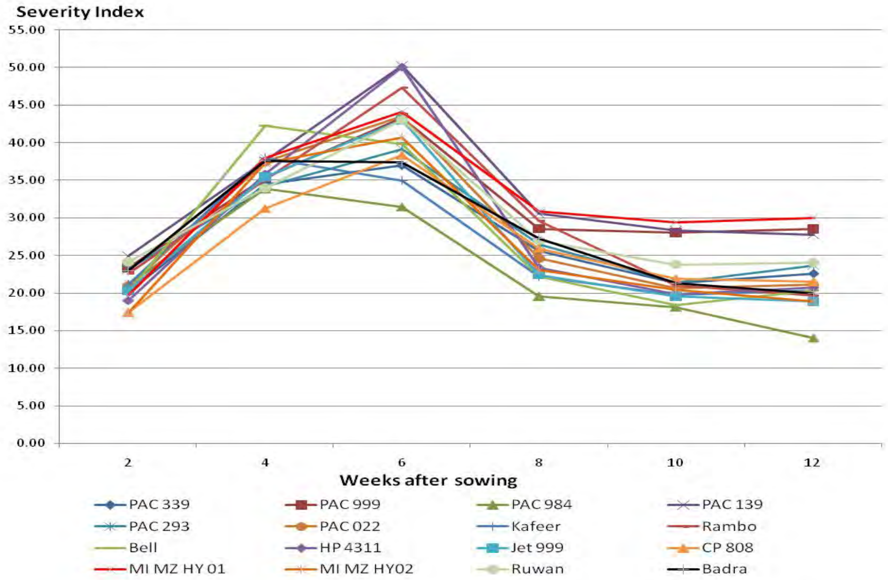

Fig.3: Severity of FAW damage after sowing in different maize varieties/hybrids tested during rainy season (Maha) 2018/19 at Mahailluppallama, Sri Lanka

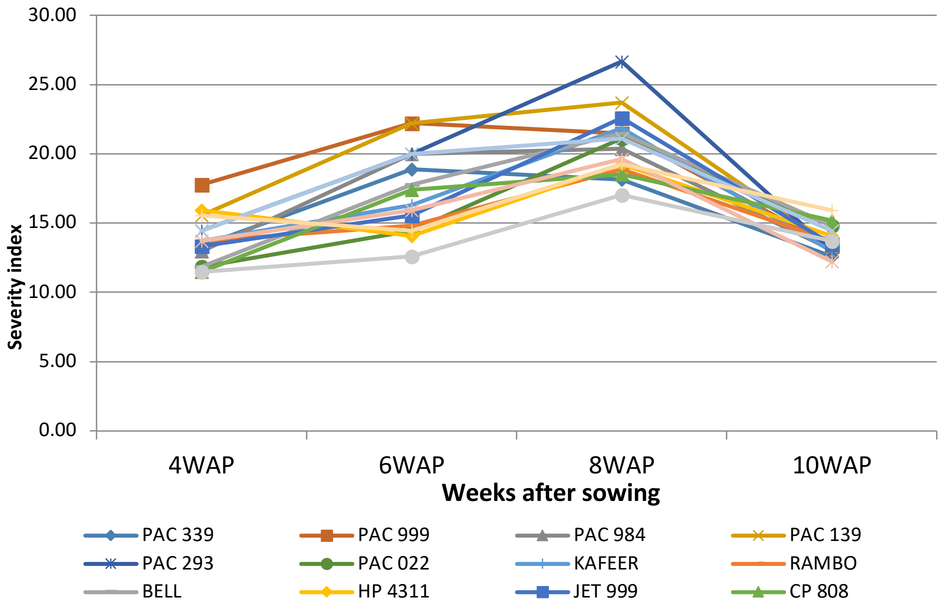

Fig.4: Severity of FAW damage after sowing in different maize varieties/hybrids tested during dry season (Yala) 2019 at Mahailluppallama, Sri lanka

Table 2. Severity indices of cob damage in different maize varieties/hybrids during rainy season (Maha) 2018/19 and dry season (Yala) 2019 at Mahailluppallama, Sri Lanka

Variety/hybrid	**Mean severity index for cob damage**	
	***Maha* 2018/19**	**Yala 2019**
PAC 339	15.8	20.37
PAC 999	12.7	17.41
PAC 984	12.9	18.89
PAC 139	11.8	17.78
PAC 293	12.5	22.22
PAC 022	11.5	21.48
Kafeer	13.0	18.52
Rambo	15.0	27.04
Bell	12.3	20.74
HP 4311	12.6	23.33
Jet 999	12.4	23.33
CP 808	12.2	23.33
MI MZ HY 01	14.0	22.96
MI MZ HY02	12.6	19.63
Ruwan	12.5	20.74
Badra	14.0	22.96
	ns	ns

Evaluation of different pheromone lures for monitoring male Fall Armyworm

Efficacy of two sex pheromone lures with bucket type traps imported from Greece (SpoFru) and United Kingdom (Russell IPM) were evaluated along with control (trap with no lure) for monitoring male FAW in maize fields. Both lures consisted of a rubber septum loaded with a pheromone blend (mixture of (Z)-7 Dodecenyl acetate, (Z)-9 Dodecenyl acetate, (Z)-9 Tetradecenyl acetate &(Z)-11 Hexadecenyl acetate

The higher number of male FAW moths were trapped in Russell IPM, UK lures than SpoFru, Greece lures. Moths were not found in traps without lure. Very few number of other moths were trapped for both lures (Fig. 5).

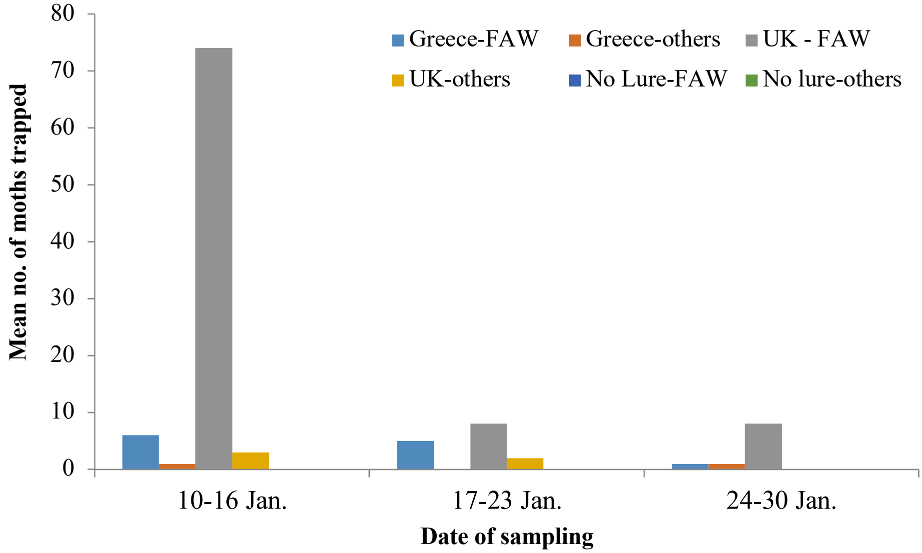

Fig. 5: Mean number of male FAW moths trapped in different pheromone lures at different sampling dates in maize

Field evaluation of the efficacy of insecticides against FAW

Thirteen insecticides were tested in 2 locations of farmers' fields during *Maha* 2018/19 season and five (Spinotoram 25%WG, Spinosad 2.5 SC Emamectin benzoate 5%SG, Chlorantraniliprole 20SC and Chlorantraniliprole 20% + Thiamethoxam 20 % WG) were recommended against FAW (Table 3).

Table 3. Effect of different insecticides on larval mortality and severity of FAW damage during *Maha* 2018/19 at two locations of farmers' fields

Treatment	% Larval mortality (3 days after 1st spray		Mean Severity index for leaf damage-8 WAS	
	Location 1	Location 2	Location 1	Location 2
Spinotoram 25%WG	97.2a*	89.5a*	6.7h*	13.8f*
Spinosad 2.5 SC	89.0a	80.3ab	12.2g	17.7ef
Emamectin benzoate 5%SG	96.4a	91.6a	8.9gh	14.4f
Etofenprox 10 EC	61.1bcd	56.8d	37.8b	35.5bc
Flubendiamide 20%WG	65.8bc	70.8bc	16.1f	28.8cd
Chlorantraniliprole 20 SC	95.0a	83.9ab	11.1g	17.7ef
Tebufenozide 20 SC	51.6de	63.6cd	31.6cd	35.0bc
Chromafenozide 5 SC	56.0cde	56.9d	35.5bc	36.1bc
Novaluron 10 EC	59.0cde	64.3cd	22.8e	34.4bc
Bistrifluron10 EC	45.4e	62.1cd	33.3cd	38.3b
Lufenuron 5 EC	73.8b	70.8bc	31.1d	37.7b
Chlorantraniliprole 20% + Thiamethoxam 20 % WG	90.5a	88.3a	11.6g	16.6f
Untreated control	0.0f	0.0e	53.8a	49.4a
%CV	9	9	8	11

*Means followed by the same letter are not significantly different at 5% level
WAS- weeks after sowing

Testing of insecticide seed treatments to control FAW in Maize

The seed treatment technique, an economical and environment safer method for protecting young seedlings/plants from pest infestation, is now widely adopted in many countries for different crops. Therefore, two seed treatments Tetraniliprole 48FS (@ 50ml/1kg of seeds) and Cyantraniliprole 47.8%SC (@ 6ml/1 kg of seeds) were tested against FAW. FAW damage was very low (below 5%) in both seed treatments applied plots up to 4 weeks after sowing compared to untreated plots (60-82%). Both seed treatments are effective at early stages of the maize crop and thereby reduces the number of foliar application of insecticides required for FAW management.

Studies on Identification and mass rearing of bio control agents

Many insects have been reported parasitizing FAW larvae and eggs. Egg Parasitoid, *Telenomus remus* (Hymenoptera: Platyastidae) was collected from Fall Armyworm eggs from farmers' field and mass rearing was done in laboratory. Field Release of Egg Parasitoid were conducted in farmer fields in 2019. Several predators such as Earwig, bugs, ground beetles, lady bird beetles that attack on larvae of FAW were identified.

New bio pesticide for the management of FAW on Maize.

One of the most promising bio-pesticides, SfMNPV (FAWLIGEN) was imported and tested under laboratory conditions and farmer field conditions and recommendation were given @ 100 - 125 ml /ha for the control of first to third instars of the larva at early stage of the maize crop. Three hundred liters of formulated product was imported and has made available for maize growing farmers.

Effect of intercropping on FAW damage in Maize

Cultural control is an important component of a pest management strategy for FAW. Intercropping maize with non-host crops may be useful to minimize the invasion of FAW (FAO, 2018b). Several intercropping systems were tested against FAW. Severity of leaf and cob damage was low in maize intercropped with cowpea and mungbean compared to maize sole crop.

5. Recommendations

The exotic hybrids, PAC 984, Jet 999 and Rambo and local hybrid MI MZ HY 02 show moderate resistance against FAW damage. Out of the two tested pheromone lures, lure from Russell IPM attracted more FAW moths and selected for monitoring FAW populations. The insecticides namely Spinotoram 25%WG, Spinosad 2.5SC, Emamectin benzoate 5%SG, Chlorantraniliprole 20SC and Chlorantraniliprole 20% + Thiamethoxam 20% WG were selected as the most effective insecticides for management of FAW. Two seed treatments namely Tetraniliprole 48FS and Cyantraniliprole 47.8%SC were identified as effective to manage FAW damage up to 4 weeks after sowing. Natural enemies of FAW associated with maize crop were identified and mass rearing of parasitoids was started. *S. frugiperd*a Nuclear polyhedrosis virus were identified as effective method to control early stages of larvae. FAW populations were significantly lower in maize intercropped systems with mungbean or cowpea compared to the monocrop.

6. Conclusions

The Fall Armyworm has recently been introduced into Sri Lanka and has become a major threat to maize production in Sri Lanka. However, yield loss caused by Fall armyworm was 10-25% during rainy season and below 5% during dry seasons. Late planted crops were heavily damaged. Severe incidence of foliar damage was observed on young stage of maize crop. However, maize plants have an ability to compensate the damage. Use of combination of methods rather than use of single control method is important to reduce the damage. Furthermore, it is important to conduct awareness among the farming communities about the life stages of the pest, scouting for the pest, natural enemies of the pest, understanding the right stages of the crop on which high economical damage may occur by FAW and the time of insecticide application and implement environmentally safer, and effective management practices for sustainable management of the pest.

7. Way Forward

In Sri Lanka, the area under maize cultivation has been expanded. Pests including Fall armyworm are considered as one of the main constraints to increase the productivity of maize crop. Insecticides are used as the first line of defense by the farmers for managing the Fall Armyworm. Therefore, it is important to develop sustainable management options based on an integrated pest management approach.

Research efforts should be undertaken to investigate the potential for biological control methods. Information on the natural enemies available should be collected. Pheromones based control methods should be developed. Strengthening of pest monitoring and surveillance system is important.

In addition, more emphasis should be given to develop better pesticide application technology as the insecticides hardly reach the pest living inside the whorl. The impact of recommended insecticides for pest resistance should be determined.

Farmers should be educated and trained to build up their knowledge and skills on pest management. Group approach through farmer training classes, demonstrations, field days as well as mass media is useful in disseminating the information.

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Chapter 10

Combatting Invasive Species: The Case Study of Fall Armyworm

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1. Introduction

An "invasive species" generally refers to an "alien" or "non-native" species that arrives in a new habitat or country, becomes established, and spreads and proliferates to such an extent that it causes one or more types of damage. Many different types of organism can be invasive. In this paper we illustrate some of the issues and approaches in responding to the threat of invasive species, using examples of CABI's work on the Fall Armyworm (FAW).

The pathway by which an invasive species reaches a new area is usually connected to human activity. Significant numbers of invasive species, including many plants but also some invertebrates and vertebrates, are introduced intentionally with some purpose or use in mind. The introduction also occurs unintentionally through contamination of commodities, shipping containers and other items that are moved long distances.

The pathway by which FAW escaped from its native area in the Americas to become widely established in Africa, Asia, and the Pacific is not known, and there is evidence that more than one such introduction may have occurred. However, in considering the appearance of FAW in West Africa, Cock *et al*. (2017) concluded that it was most likely FAW arrived as a stowaway, or possibly as a commodity contaminant. Prior to its appearance in Africa in 2016, FAW had been regularly intercepted arriving in Europe on commodities such as *Capsicum* and *Solanum* imported from Central and Southern America, providing evidence that commodity shipments are a potential pathway of introduction.

A further pathway through which invasive species spread is natural dispersal. FAW is a strong flyer, and studies in the Americas have shown that it can travel hundreds of kilometers, allowing it to reach northern parts of USA and Southern Canada from its overwintering areas in Southern Texas and Florida. While it is unlikely that FAW crossed the Atlantic unaided, the rapid subsequent spread within Africa and Asia suggests that natural dispersal played a role.

Until the coronavirus pandemic, expanding trade and travel were increasing the opportunities for species to be introduced outside their native ranges. Additionally, climate change makes new habitats suitable for invasive species, although climate change is not thought to be a factor in the sudden spread of FAW, as modeling indicates large areas of Africa and Asia are suitable for the pest (Early *et al.*, 2018). Although FAW is a particularly dramatic example of an invasive species, it is only one of many, and more can be anticipated. While a response to the threat of FAW is critical, we suggest it also provides the opportunity to learn lessons and so be better prepared to respond in the future.

The threat posed by invasive species, and the need for coordinated action, is not new. As long ago as 1881, a group of countries signed an agreement to limit the spread of an aphid (*Viteus vitifoliae*) that had been accidentally introduced to Europe from North America, causing severe losses to vineyards. Subsequently, the International Plant Protection Convention (IPPC) was established in 1952, "With the purpose of securing common and effective action to prevent the spread and introduction of pests of plants and plant products, and to promote appropriate measures for their control" (Article 1). There are over 180 contracting parties to the convention, who undertake to adopt legislative, technical and administrative measures specified in the convention.

In 1992, the Rio Earth Summit resulted in the establishment of international conventions on biodiversity, climate change and desertification. Article 8(h) of the Convention on Biodiversity (CBD) concerns invasive species, requiring each party (over 190), as far as possible and as appropriate, to "Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".

Thus, invasive species are a widely identified problem, and most, if not all countries affected by FAW, are already parties to the IPPC and CBD, so are expected to collaborate in responding to the threat it poses.

2. Strategies for Managing Invasive Species

Different strategies are appropriate for addressing the threat of invasive species at different phases of an invasion (Fig 1). Prior to the invasion, prevention, or taking steps to stop an invasive species from entering is required. This may involve horizon scanning and or risk analysis to assess which species should be targeted with preventative measures. At this stage preparedness or contingency planning is also appropriate so that if an invasion occurs, the response can be swift and effective. Once a species arrives, if it presents a high risk then emergency measures are required. Eradication is sometimes feasible, particularly if the invasion can be caught in its early stages, so early detection and rapid response are required. If eradication is not possible, containment in the area of original infestation might be feasible. Once an invasive has become more widespread and is firmly established, pest control and mitigation of the adverse effects is the appropriate strategy. In general, prevention is the more cost-effective strategy. The rest of the paper provides examples of CABI's work at the different phases of the FAW invasion.

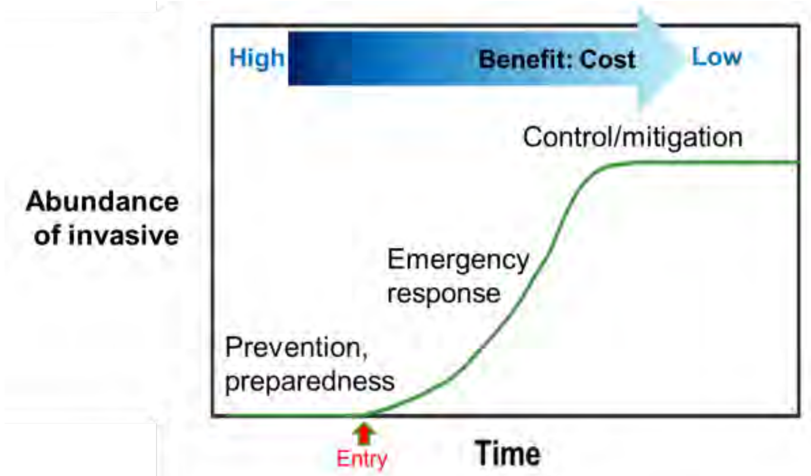


Figure 1. Strategies for addressing invasive species in relation to the phase of invasion (adapted from State of Victoria, 2010)

3. FAW Prevention and Preparedness

Ideally, an invasive species such as FAW would be recognised as a risk before it arrived in a country. There are various tools with which to try and identify potential risks, a general process known as horizon scanning. CABI's Horizon Scanning Tool (HST) assists in this process by providing a list of all the invasives in CABI's global database that are not listed as present in a particular country (or other specified area). That list can then be filtered; for example, a geographic filter could be applied to narrow the list to those species that are present in neighbouring countries. Other filters include host plants and taxonomic group. In a review of the tool, Boice (2021) concludes the tool "is recommended for those investigating risks from invasive species and for information professionals supporting them". CABI has provided initial training in horizon scanning to the NPPO in Pakistan, and further work is planned.

Species identified by the horizon scanning tool as potential risks might be subjected to a full pest risk analysis (PRA), a process which CABI's PRA Tool supports (www.cabi.org/PRA-Tool). But with or without a full PRA, the identification of a potential risk allows for preparedness and contingency planning.

In the case of FAW, few if any countries in Africa had identified it as a potential threat, despite it being a widespread and serious pest of maize in the Americas. Thus when it was first detected in the continent (Goergen *et al*., 2016), it caught many countries unprepared, although those that were invaded later did have some opportunity to prepare. The situation was somewhat different in Asia. By the time FAW was detected in India in 2018 (Sharanabasappa *et al*., 2018), there had already been two years' of experience from Africa, from which it was clear that Asia did indeed need to be prepared.

CABI supported preparedness and contingency planning in Asia in a number of ways. Before FAW arrived in Asia, CABI alerted 11 countries on the possible future invasion of the pest, and provided information to support planning. A comprehensive "Evidence note" (Abrahams *et al*., 2017) prepared for Africa and then updated (Rwomushana *et al*., 2018) proved to be a useful resource. Part of that document included environmental suitability mapping to assess which parts of the world would be most suitable for FAW, and to assist Asian countries with their preparedness, regional and country maps were made available (Figure 2).

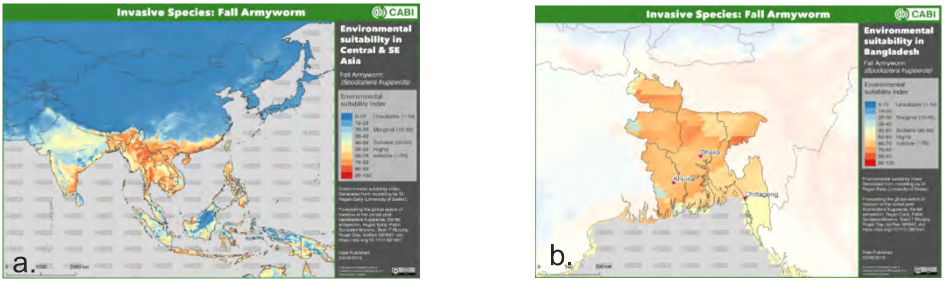


Figure 2. Environmental suitability for FAW (a) in Asia and (b) in Bangladesh. Maps available from www.cabi.org/ISC/fawenvironmentalsuitabilitymaps

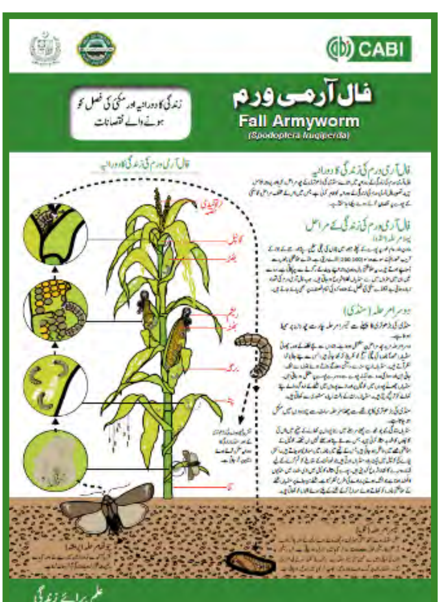
Support was also provided to individual countries; for example in India assistance was provided in drafting the proposal for a national contingency and response plan.

4. FAW Emergency Response

Once a new invasive species have been detected, a rapid response is desirable, which is facilitated by having a plan already in place. A key initial step is to confirm the identity of the invasive species. In the case of FAW, confirmation of the identity is best done using molecular methods, and CABI provided a molecular identification service to a number of countries.

Another step that is often taken soon after a new invasive is detected is to conduct a delimiting survey, to ascertain the extent of the outbreak, and how widespread it is. If the species spreads slowly, and is confined to a small area, eradication might be considered, or at least containment to stop it from spreading to other parts of the country. However, for FAW, which is highly mobile and spreads rapidly, it is not surprising that no country has considered eradication feasible. For most countries there was little time between the recorded entry of FAW and it becoming widespread, reaching the level at which control and mitigation was required (Fig 1).

Effective communication is required at all stages of an invasion, and CABI and partners have developed a framework for communication during pest outbreaks, based on experience with FAW (CABI, 2019). The International Plant Protection Convention has also prepared a guide on communication of pest risks (FAO, 2019). Part of an emergency response is to ensure that stakeholders, and particularly farmers and extensionists are aware of the new pest so that it is not confused with other similar pests. CABI assisted national programs to produce a range of communication materials to build awareness of the new pest (Figure 3), with an initial emphasis on recognising the pest and understanding its life cycle.



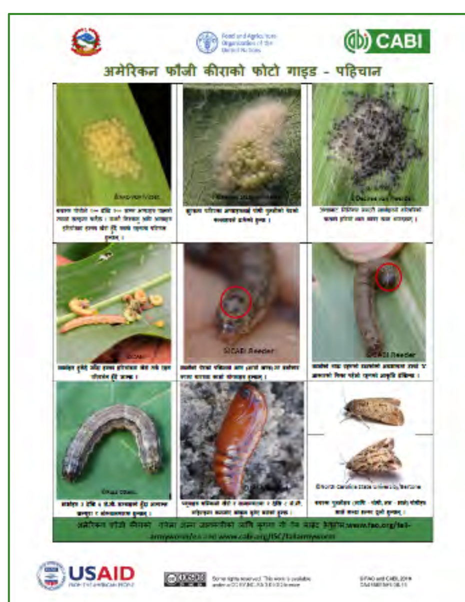


Figure 3. Examples of awareness posters on Fall Armyworm life cycle and identification

The emergency response also entails the selection of management methods to promote and implement. In the case of FAW, it has been seen that in the absence of practical alternatives, many farmers have turned to pesticides. To counter this tendency, CABI published a review of biological pesticides for FAW (Bateman *et al.*, 2018), indicating priorities for the short and longer term. The review has subsequently been updated (Bateman *et al.*, 2021).

5. FAW Mitigation and Management

In almost all countries invaded by FAW, populations rapidly spread and built up to the extent that mitigation and management was the only feasible strategy. Although FAW may become less serious through time (for example due to the build-up of local natural enemies), it is clear that when and how to control the insect will be ongoing questions for some time. This requires a range of activities related to research and development, as well as communication and extension.

To understand and address what helps or hinders communities in adopting recommended practices for managing invasive species, CABI built several activities into its flagship programs Action on Invasives and Plantwise. These activities were primarily aiming to develop the knowledge and capacity of extension workers, farmers and agro-dealers on FAW management. Mass extension campaigns to promote effective management of fall armyworm, were conducted in Afghanistan, Bangladesh, India, Sri Lanka, Nepal and Pakistan, reaching nearly 0.5 million people, supported by a range of communication materials using print, video, mass and social media.

Although there is general agreement that Integrated Pest Management (IPM) is the appropriate strategy for FAW control, in many cases the commonest control method being used is pesticides, sometimes using highly toxic chemicals. In part this is because pesticides are readily available, whereas IPM and its components take time to develop and disseminate. The various approaches to biological control (conservation, augmentation, classical) can all be considered as part of IPM, and CABI has been providing support in this work in Asia as well as Africa. Biocontrol approaches all require surveys of natural enemies in the invaded areas, to understand what species are present, and to identify opportunities for conservation and/or augmentation, as well as assist in assessing suitable candidates for introduction. Significant egg and larval mortality has been found to occur due to natural enemies already present, but this is affected by pesticide use, cropping systems, and agronomic practices. The first trials of augmentative biological control with egg and larval parasitoids of fall armyworm have been conducted in Bangladesh, but a cost-effective solution cannot be recommended yet. A technical manual on the production of biocontrol agents for FAW was published with Bangladesh Agricultural Research Institute (BARI). *Eiphosoma laphygmae*, a parasitoid of fall armyworm from the Americas (Allen, Kenis and Norgrove, 2021), has been found to be host-specific in laboratory trials, and so has good potential as a classical biological control agent. Shipments have been made to Pakistan, where cultures have been established for further tests prior to application for field release.

Several biopesticides are now known to be effective for fall armyworm control, but registration of these products is patchy, and they are still not available in many countries. CABI has therefore been facilitating these processes where possible. In Pakistan, a workshop was held with private and public sector organizations to review new regulations on biopesticide registration in the context of fall armyworm management. The workshop prioritized eight biopesticides, none of which is currently registered in the country. A desk review of biopesticide regulations was also conducted in Bangladesh. Microbial pesticides are covered under the Pest Control Products Act, which provides for biopesticide registration procedures similar to those used for chemical pesticides, which could be an impediment to microbial pesticide registration. However, Fawligen, the nucleopolyhedrovirus specific to the fall armyworm, has been rapidly registered in the country.

CABI has also developed an online BioProtection portal (https://bioprotectionportal.com) to make information on bioprotectants and biopesticides more widely available, with the aim of facilitating their uptake. The BioProtection Portal is a free, web-based tool that enables users to discover information about registered biocontrol and biopesticide products around the world. Among SAARC countries, the tool currently has data for Bangladesh and India.

6. Coordination and Collaboration

Effective international, regional, and national coordination is required to address a major invasive species such as FAW. Internationally, FAO has taken a leading role in this respect, and CABI has supported that effort, particularly through the thematic working groups on Farmer Communication and Awareness, and on Biological Control. Under FAO's Global Action on FAW, CABI has been part of the IPPC Technical Working Group that has prepared guidelines for FAW prevention, preparedness and response (IPPC Secretariat, 2021). Regionally, CABI organized the first regional conference on FAW in Nepal in November 2018, where NPPOs from South and South East Asian countries participated along with other international partners such as CIMMYT and FAO. CABI has also collaborated with CIMMYT in the preparation of a video "Biological

Approaches for Management of Fall Armyworm", and sharing of knowledge and experience within the region has also been promoted through facilitating links between ICAR and BARI.

After learning of the pest, several countries including India, Bangladesh called for high-level planning meetings under the senior leadership of Ministries of Agriculture (MoA) and National Agriculture Research Systems (NARS) to deliberate on the current status of the pest and possible interventions. Through these planning meetings CABI has been able to provide a range of support to SAARC countries, including Bangladesh, India, Sri Lanka, Nepal and Pakistan. The support has been in the areas identified above, covering both preparedness, as well as emergency response and mitigation, including communication and establishing research and development activities.

A key part of coordination and collaboration is information exchange, and CABI has provided two on-line resources to promote information sharing specifically on FAW. A FAW information portal has been established within the free-to-access Invasive Species Compendium (www.cabi.org/isc/fallarmyworm) containing resources from multiple organisations. The resources include guides, factsheets, manuals, videos, posters, leaflets, covering identification and management of FAW. Abstracts of recent research on FAW are also included from CABI's global abstracts database.

To promote collaboration in FAW research, a FAW Research Collaboration Portal (https://faw.researchcollaborationportal.org/) has been set up which allows users to post research notes, contribute to a crowd-sourced database of natural enemies, post or answer questions, and find collaborators.

7. Way Forward

Now that FAW is widespread within the SAARC region, mitigation and control through integrated pest management is the approach that must be adopted. However, in general, IPM has been found difficult to implement for a number of reasons. In the case of FAW we suggest that developing and implementing successful IPM, a collection of tools for local adaptation and application by farmers, will comprise a number of key elements.

Research is needed on non-chemical approaches to management, including agronomic practices, pest-resistant host plants, bioprotectants or biopesticides, and biological controls including conservation and encouragement of existing natural enemies, augmentation through the release of reared natural enemies, and classical biological control. For augmentation, business models for local production and distribution of natural enemies should be investigated.

Control methods requiring specific inputs are more likely to be adopted when there is a private sector organisation that can make a business out of their promotion and sale. Therefore, involvement of the private sector from the inception of research through to implementation of various programs will increase the likelihood that the needs of farmers are being met and that economically sustainable control of FAW can be achieved. Regulation and policy should be reviewed to ensure they promote the development and use of environmentally sustainable and lower risk control products, which will benefit the management of other species as well as FAW.

Effective, two-way communication is required so that the different stakeholders, including farmers, can collaborate and cooperate locally, nationally, regionally and internationally. No single stakeholder group holds all the knowledge, so sharing of information and experience supports rapid progress.

Finally, we emphasize that while FAW is a particularly serious invasive species, it is not the last invasive pest that will affect crops in the SAARC region. It is therefore important that lessons are learned from FAW, so that when the next invasive species arrive, countries and the region will be better able to respond and minimise the cost to smallholder farmers. In this regard key activities to which more priority should be given are horizon scanning and the identification of potential risks, risk analysis, and contingency plans. Even without the risk identification and analysis, countries should develop a generic contingency plan, and SAARC could also develop a regional one, both of which would greatly improve the response to any invasive species. The multi-stakeholder task forces that have been established to address FAW could perhaps become invasive species task forces.

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Chapter 11

Implications of invasion for integrated pest management: learning from Fall Armyworm in Bangladesh and South Asia

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1. Introduction

The invasive crop pest, Fall Armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), has gained international attention as it spread from the Americas through Africa and then to Asia between 2016 and the present. The pest, which is broadly polyphagous but prefers maize (*Zea mays*), was first recorded in the state of Georgia in the United States in 1797, after which several outbreaks occurred during the nineteenth century at a wider distribution in the Americas (Johnson, 1987). In 2016, it was first reported outside the Americas in West Africa – first in Nigeria – and within three years it had spread to more than 40 countries in Africa (Sisay *et al*. 2019). Estimates are that FAW destroyed more than 13.5 million tons of maize worth USD 3 billion in Sub-Saharan Africa before reaching South Asia (Abrahams *et al.* 2017), recorded first in Bangladesh in late 2018 (Alam *et al.* 2018). Experience in Africa indicated that the years following establishment can result in increasingly significant crop losses as populations establish and build up; as such, response mechanisms are needed to rapidly raise awareness of integrated pest management (IPM) options – including pest monitoring, cultural and mechanical control, as well as biological control and implementation of biological and low-toxicity pesticides – that are suitable for invasive species such as FAW.

This chapter documents learnings from the USAID/Bangladesh and Michigan State University's Borlaug Higher Education for Agricultural Research and Development (BHEARD)-supported 'Fighting Fall Armyworm in Bangladesh' project, which is led by the International Maize and Wheat Improvement Center (CIMMYT) to support the public and private sectors to achieve more effective FAW mitigation. The project has been working since late 2019 in collaboration with a range of national public and private institutes to achieve six mutually supportive objectives, resulting in more than 187,000 farmers receiving FAW IPM advice as a result of cascade trainings[1] and the raising of awareness of at least 133,000 more farmers on FAW IPM through media campaigns. Over a period of xx years, women extension agents were engaged to become IPM experts, with 107 women leaders in IPM training 2,530 colleagues in the Bangladesh government's Department of Agricultural Extension (DAE) who went on to reach over 17,000 farmers with IPM advisories. Two leading pest management companies began offering FAW crop consultant services to farmers – one of them focused on the use of biological pesticide that was registered for commercial use with the support of the project – and a comprehensive population monitoring system of FAW and open-access data dashboards were developed. The Fighting FAW project also increased the leadership abilities of strategic partners within the Government of Bangladesh of Bangladesh, readying them to step up when an emergency pest response to FAW and future threats is needed, while also supporting IPM research. The project activities are near to the end and some of the key learnings are documented in this chapter.

2. Background to FAW's distribution and its consequences in South Asia

Although maize is FAW's most preferred host, reports of the pest having been found on rice, sorghum, cotton, tobacco, cabbage, tomato and sugarcane have been recorded from India, Bangladesh and Sri Lanka, although causing relatively low levels of economic damage (Lamsal *et al.* 2020). The degree to which FAW can survive, reproduce upon, and cause considerable economic losses to these cultivated species has however not yet been widely studied in Asia. In addition, the overwhelming preference of FAW for maize indicates that – for the moment – the pest is unlikely to reproduce in large numbers or cause significant damage to rice, which is the major staple crop in South Asia (Lamsal *et al.* 2020).

It is likely that FAW arrived in Africa through international trade (Sisay *et. al.* 2020). Debate however remains as to how it established itself in Asia following incursion across Africa (Chormule *et al.* 2019), although sub-tropical, tropical and warm weather conditions, with mean annual temperatures ranging from 17°–35° C and annual rainfall ranging from 0–400 mm are conducive to its spread (CABI 2020). Although many parts of South Asia have rainfall in excess of these levels, the distribution of precipitation is strongly mono-modal, with a pronounced monsoon followed by a dry winter season which, relatively speaking, constitute highly suitable conditions for at least part of the year. The pest is also known to

[1] All trainings referred to in this paper and conducted by CIMMYT since the start of the Covid-19 pandemic have observed government restrictions, and guidance on Covid-preventative measures.

migrate from cooler to warmer temperatures for overwintering because it cannot survive below 10° C for extended periods (Sparks, 1979; 1986). These characteristics render a large proportion of South Asia favorable to FAW for at least part of the year (Figure 1).

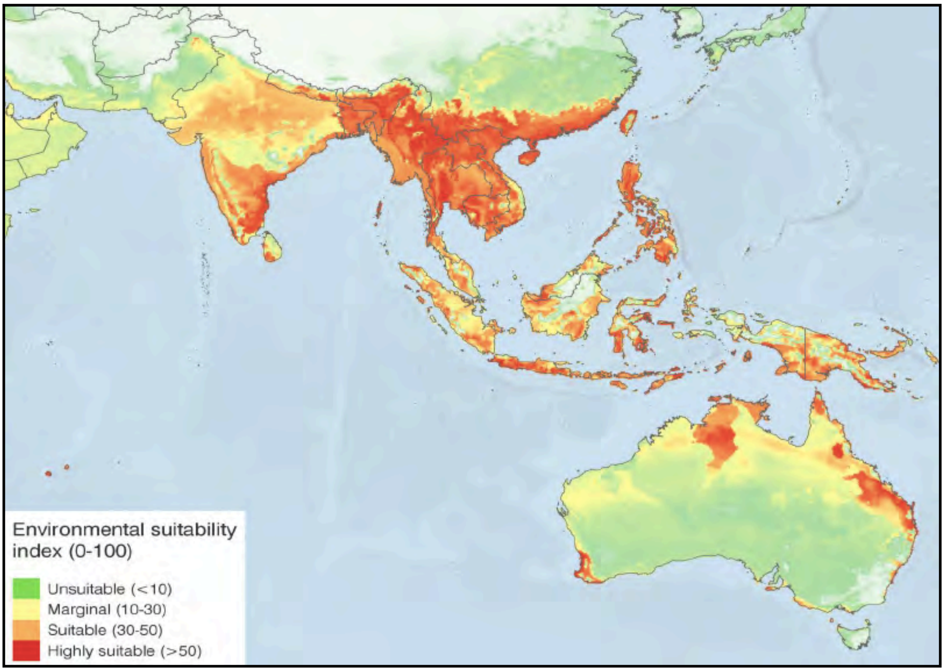

Figure 1: Environmental suitability for FAW to breed in South and South East Asia and Australia (mapping courtesy of CABI Biosciences).

In addition to being polyphagous, there are a number of reasons that make FAW a challenging pest to manage, including that (a) with a nocturnal feeding habit, FAW tends to hide from upper leaves during the day, preferring to burrow between leaves and stems, (b) it pupates underground, (c) under sub-tropical and tropical conditions, FAW has a high reproductive rate and a (d) large range of environmental and habitat suitability, and (e) can travel hundreds of kilometers in one insect's lifetime (Johnson, 1987). Farmers in Asia also tend have broader access to agricultural input markets and pesticides than those in Africa; as a result, many have resorted to the use of relatively toxic and often inappropriate insecticides in an attempt to control FAW (Lamsal *et al.* 2020). This has important and potentially negative consequences for human and environmental health, in addition to often being poorly effective, as the management of FAW requires very specific techniques that are tuned to the pest's habits and characteristics. For these reasons, employing IPM strategies that rely on cultural and biological management techniques should be paramount, with the integration of the least toxic synthetic insecticides included only as a last resort when and where absolutely needed. This chapter reviews some of the lessons learned over the last two years in facilitating IPM as a response to the invasion of FAW. Although we focus on experiences in Bangladesh, many of the points discussed below have broader relevance across Asia and Australia.

3. Key lessons in appropriate FAW response

3.1. Confronting the 'spray first, think later' mindset

Different pests have different damage characteristics and severity. Sudden outbreaks of an invasive species that causes highly apparent damage – such as FAW – tend to create alarm among farmers. As pesticides are quite widely available in South Asia, including Bangladesh, many farmers have been historically reliant on synthetic chemical pesticides that are used for pest control (Antel and Pingali, 1994), with indiscriminate and excessive use common in many areas. This raises concerns regarding the risk of pesticide resistance development (Diez-Rodríguez and Omoto, 2001; Ahmad *et al.* 2018; Wang *et al.* 2018), and as many farmers do not maintain a waiting period after applying pesticide before re-entering the field or harvesting, farmers and consumers may In response, IPM is one of a number of approaches that are gaining credibility as a pillar of sustainable crop management (Chimweta *et al.* 2020). IPM involves the integration by farmers of the most appropriate and localized management strategies for pest control, with the goal of leveraging ecological services to regulate pests while reducing dependency on chemical pesticides. The inclusion of the term 'integrated' in IPM is important, as no single approach (or proverbial silver bullet) should ever be considered appropriate or effective for pest control.

As noted above, FAW favors maize as its preferred host (Sisay *et al.*, 2019). This presents a challenge because (a) maize production in South Asia and particularly in Bangladesh is growing (BBS Annual report, 2019), (b) FAW can cause serious crop losses, and (c) the development of resistance to commonly used chemical pesticides has been observed in FAW (Lamsal *et al.* 2020), indicating the risk of rapid carry-over of resistance genes to subsequent generations and regions, given FAW's rapid life-cycle and long-range distribution. In addition, (d) the indiscriminate use of broad-spectrum chemical pesticides can result in serious environmental and human health problems and pest resurgence (Michelotto *et al.* 2017, Antel and Pingali, 1994) (Figure 2).

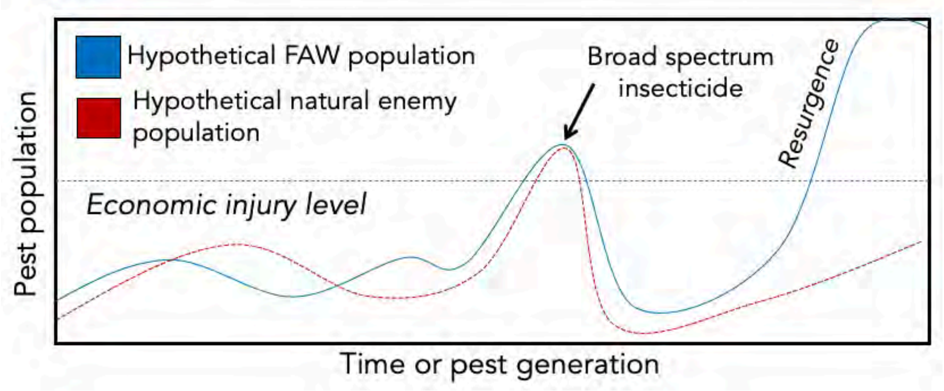

Figure 2: Hypothetical pest and natural enemy populations over time and their fluctuation caused by broad spectrum insecticide use that can cause resurgence.

IPM approaches should integrate host plant resistance and agroecological management (Harrison *et al.* 2019) (although it should however be noted that there are currently no viable options for ensuring maize plant resistance to FAW in Asia). Biological control is one of the most important components of IPM, which works through promoting the natural enemies of the key pests of crops, thereby offering a sustainable, viable and ecological solution to the pest problem. In addition to managing agroecosystems so that they favor pest suppression through conservation and augmentative biocontrol, biological pesticides can play a role in IPM in South Asia. These are products manufactured from natural sources such as animals, plants and micro-organisms, and include so-called 'bio-rational' 'natural ingredient pesticides,' 'micro-organism pesticides' and 'biochemical pesticides' which tend to have lower toxicity rates than many synthetic pesticides and may be used to manage pests intelligently (Bateman *et al.*, 2018). Because they are based on the ecological interaction between the pest species and the biological source of the pesticide, these products tend to be species-specific rather than broad-spectrum (Figure 2). As such, they are arguably more appropriate from an environmental standpoint as they lack significant non-target effects on other species (Sparks. 1986). Furthermore, they decompose more quickly in the environment than conventional synthetic pesticides, and hence are less persistent. In response to the increasing emphasis on the need for agroecological management options to foster biological control, and when pest populations and rates of attack are sufficiently high to warrant use of pesticides, these 'bio-rational' options should be the first priority before the use of synthetic products. As such, intensive and systematic research and development is required to support the mass production, storage, transport and use of these products as an intelligent alternative to the commonly available, more toxic, and frequently broad-spectrum products (Figure 3).

Figure 3: Product advertisements for Fawligen (a bio-rational *Spodoptera fruigiperda nucleopolyhedrovirus* virus pesticide) registered for commercial use in Bangladesh with support from the Fighting Fall Armyworm project. Fawligen is now sold by Ispahani Agro Limited.

3.2. Raising the awareness of farmers and input dealers of options for FAW management

Increasing awareness of the principles of IPM is a prerequisite for ensuring an improved FAW response, and below we describe examples of how mass media can be used to raise awareness of IPM for combatting FAW. Through the Fighting FAW project, CIMMYT partnered with the NGO Agricultural Advisory Society (AAS) to organize public video showings of Bangla language educational films on the principles of FAW management. These rural video shows were set up in markets, farmers' clubs, tea stalls and other public places. They attracted an audience of more than 133,000 farmers – 22% of whom were women – who watched the video and took part in post-video question-and-answer sessions facilitated by trained technical staff using microphones and sound-boxes. The project also developed technical materials and a rapid one-day awareness-raising training for agricultural input dealers in 10 major maize-growing districts of Bangladesh (January–February 2020) were arranged, in partnership with Bangladesh's Agricultural Input Retailer

Network (AIRN). A total of 1,047 retailers from nine districts participated, each one subsequently reaching at least 50 farmers with information on FAW management. This means that more than 52,000 farmers were able to access enhanced advice on FAW management through trained dealers, who also distributed 109,000 infographics on FAW.

Mass awareness through media and rural video shows

Through synergistic activities with the CSISA project, a video produced by Michigan State University, USAID and CIMMYT on FAW management was shown to over 130,000 farmers throughout much of the maize-growing area of Bangladesh in village and road-side video shows during the *rabi* season, 2019-20. These screenings doubled as an opportunity for light training, as farmers were encouraged to ask questions with answers provided by subject experts associated with CSISA in-between runs of the video (Figure 4A).

Figure 4 (A): A public FAW IPM video show in Bangladesh.

Figure 4 (B): Distribution of informational information on FAW IPM to the audience.

In addition, 436,060 sets of FAW informational leaflets published by CIMMYT were distributed among the farmer audience (Figure 4B). In response to the COVID-19 pandemic restrictions, the project adopted an alternative means of dissemination, collaborating with cable television operators in major maize growing districts and securing their agreement to broadcast the FAW videos[2] (Table 1).

[2] Across Rangpur Division, the videos were shown from 14 January to 14 February 2021. In Khulna Division, they were broadcast twice, in October 2020 and 9 January–9 February 2021. They were shown between 4.15–5.15 pm and 5.45–6.10pm.

Table 1. Television networks in Bangladesh airing Fall Armyworm learning videos during the COVID pandemic.

Network name	Division	Districts covered	Number of sub-districts covered
AMC Digital	Rangpur	Dinajpur	9
Prime Cable	Rangpur	Rangpur	2
		Nilphamari	2
TCN Digital	Rangpur	Thakurgaon	6
Chuanga Vai Cable	Khulna	Chuadanga	4
Kotchandpur Vai Cable Network	Khulna	Jhenaidah	1
Kashripara Cable Operator		Meherpur	3

Leveraging the Private Sector

Despite the large-scale network of extension services maintained by DAE in Bangladesh, farmers commonly seek pest management advice directly from agricultural input dealers and pesticide companies. Within the private sector however, prior to the start of the Fighting FAW project activities, awareness and understanding of the biology and ecology of FAW was limited. The same could have been said for knowledge of appropriate mitigation options, including 'bio-rational' pest management options. Companies also tended to miss out on new opportunities to provide quality IPM advice directly to farmers as part of their overall business strategy. To address these issues, the Fighting FAW project worked to increase private sector capacity and awareness of integrated management approaches to FAW in Bangladesh. This was achieved through training programs for retailers, dealers and field level pesticide company officials, as well as support for the registration of 'bio-rational' and low-toxicity pesticides.

In Bangladesh, the registration process for pesticides typically takes a long time. Efficacy field tests are required for two year-seasons (24 months) and in two locations, in addition to a battery of laboratory toxicity tests and verification by National Agricultural Research System scientists to ensure data quality. Although designed to facilitate farmer and public safety, this presents challenges to the release of appropriate pesticides – including biological and botanical pesticides, which are *de facto* non-toxic – in emergency situations such as FAW invasion. The direct involvement of the project meant that a safe and effective pesticide, *Spodoptera fruigiperda* nucleopolyhedrovirus (Fawligen, SfNPV, produced by the Texas-based AgBitech and sold locally by Ispahani) was registered in less than eight months and is now being made commercially available to farmers in Bangladesh. This notable achievement resulted from the project's market systems facilitation, which serves as a benchmark example of what can be achieved when public and private sector efforts are coordinated in emergency invasive species pest response (Figure 4). Careful business planning and advertising campaigns were deployed during 2020 and 2021, resulting in the import and sale of Fawligen, which within two months had been used by over 4,000 farmers as a safe, biological alternative to dangerous synthetic insecticides (Box 1).

Box 1: Bringing a biologically-based alternative to chemical insecticides for FAW to the market

Fall Armyworm (FAW) is an invasive agricultural pest that arrived Bangladesh in 2019 and has a devastating preference for maize. Its effects can be jaw-dropping: the fields it attacks can incur significant damage to the maize leaves and cobs. This shocking sight causes farmers to panic and rapidly resort to highly toxic and expensive chemical pesticides, putting the health of both farm workers and the environment at risk. In response, the Fighting FAW project partnered with AgBiTech, a US-based agricultural biotechnology company that produces high-quality biological insecticides which reduce the need for dangerous chemical sprays. Biologically-based insecticides can be both affordable and safe to use, as well as being targeted for the control of specific pests, like FAW. The project linked AgBiTech to Bangladeshi company Ispahani Agro Limited as a local distributor, and by collaborating closely with the government's Bangladesh Agricultural Research Institute and Department of Agricultural Extension, was able to get Fawligen, a biologically-based and safe-to-use alternative to synthetic pesticides for FAW, registered for commercial use in just eight months – a record time for Bangladesh. Only minute doses of Fawligen are required to control FAW, which offers significant economies of scale. Isaphahani sold 90 liters of Fawligen in Bangladesh in two months, which have been used by over 5,500 farmers as a safe, biological alternative to dangerous synthetic insecticides. "These results are really encouraging: now we're looking to boost our partnership with Bangladesh and expand the volume of sales in the coming seasons," commented Shachi Gurumayum, Head of South Asia for AgBiTech.

3.3. FAW monitoring to provide actionable information for IPM decision-making

A key lesson learned from the challenges in Africa that resulted from the invasion of FAW is that effective pest and crop damage monitoring is crucial

(Abrahams *et al*. 2017). This section details the project's efforts to engage public extension systems in FAW monitoring in Bangladesh, with key insights that can be applied in other countries.

Comprehensive pest monitoring app

In late 2019, the Fighting FAW project developed an app: the Bangladesh Fall Armyworm Monitor. The app is custom designed, based on the requests of the National FAW Task Force and DAE in particular, to monitor the FAW population and crop damage in the country's nine major and 16 minor maize-growing districts. Extension agents collected data on damage to maize and FAW populations using inexpensive pheromone lure water traps, from 777 fields weekly from across major maize growing areas in Bangladesh, with the data uploaded and analyzed automatically in a dashboard format to enable policymakers and extension staff to make better decisions and advise farmers more appropriately. This required considerable efforts in coordination with DAE, with 250 lead monitoring staff undergoing intensive three-day residential training to learn how to collect and report quality data. This is the first time that digital tools were used for the large-scale surveillance of pests in Bangladesh, and they were widely seen as a major contributor to the project. The monitoring tool – which allows users to study population and damage trends at national, division, district and sub-district levels, and which is updated weekly – has also been expanded to Myanmar through investment from the CGIAR Research Program on Maize (MAIZE) (Figure 5 & 6).

Figure 5: (A) Training extension agents in the principles of field monitoring for FAW damage. **(B)** Extension staff checking maize plants for FAW damage. **(C)** Entering field data into the mobile app.

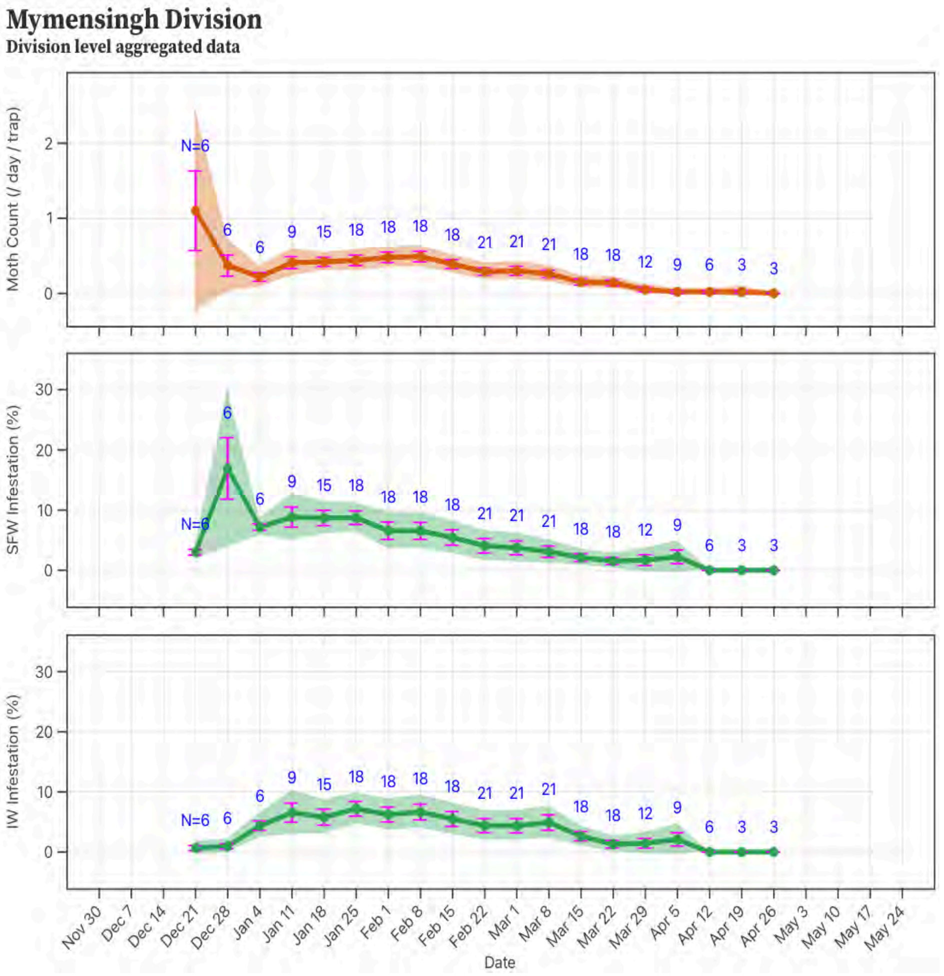

Figure 6: Example of data representation on the Fall Armyworm Monitor, from the 2020-21 winter maize season in Mymensingh Division. Shaded areas are 95% confidence intervals. Bars represent the standard error of number of observations made (depicted as N) in the graphs above.

Extension staff in these countries make use of the simple-to-interpret graphs of population dynamics and use them to aid discussion with farmers who are contemplating spray or no-spray decisions. Importantly, in the first season during which the app and dashboard were deployed, cohorts of trained extension agents advised farmers not to use insecticides and instead to rely on biological control three times more frequently than they had previously done (FAW Report 2020, anonymous). In addition, partnerships with Bangladesh Agricultural Research Institute (BARI) and Bangladesh Rice Research Institute enabled similar monitoring of cabbage, tobacco, rice and tomato crops.

Solar-powered digital FAW monitoring option

Manual observations of FAW populations from traps like those maintained by DAE can be time-consuming and difficult, and although the project has had considerable success in mobilizing national FAW monitoring, in the long-term, less time and cost intensive methods will be needed. To this end, the project has set up a test of three solar-powered, self-cleaning and auto-count traps made by the company Trapview inside three maize fields in Chuadanga, Bogura and Dinajpur (Figure 7).

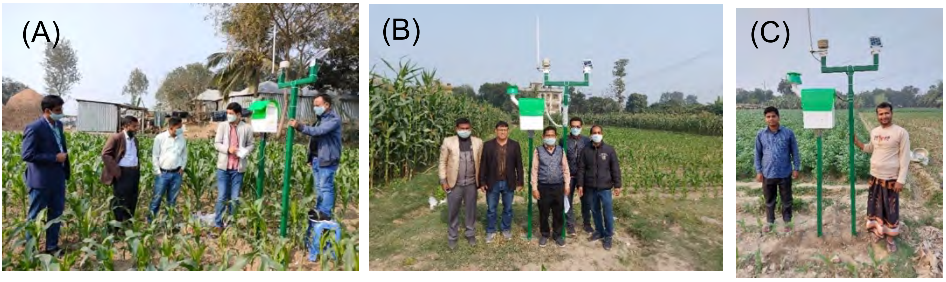

Figure 7. (A) BARI scientists learning about the installation process of the trapping device in Bogura. **(B)** Bangladesh Wheat and Maize Research Institute (BWMRI) entomologists and project colleagues after Trapview installation training in Dinajpur. **(C)** A DAE representative and farmer who were present during the installation of the device in Chuadanga.

The traps come with associated software which provides high resolution images taken from the trap and includes machine-learning-aided automatic FAW population counts from photos taken within the device. This is all accomplished without intervention by monitoring staff. At the time of writing, the use of these traps and software are being tested to determine their efficacy in producing automated pest counts, and to judge whether the traps can be used to trigger alarms on pest status. The Chuadanga and Bogura devices were established in a farmer's field, with the final one set up on the farm at the BWMRI Dinajpur research station. In conjunction with all the devices, FAW lures were used exclusively to monitor FAW. All the devices are fully functional, with each one generating daily pest photos along with a weekly pest accumulation report sent automatically by email to DAE staff. Among project partners, these traps have so far been quite popular as a digital monitoring device and proved capable of producing accurate data. Hopes are that following verification of the data, Bangladesh's national research and extension institutes can start using this device to monitor FAW and other invasive pests, more accurately and efficiently.

3.4 Developing extension services capacity to respond to FAW with IPM advice

Training for master trainers

In 2019, 2020 and 2021 during Bangladesh's winter *rabi* and summer *kharif* maize seasons, the project arranged a series of intensive three-day residential field trainings in integrated FAW management. These were designed as master 'trainer of trainers' sessions, to develop master trainers who were expected and mandated by DAE to pass on their learning to other extension staff and farmer group leaders by implementing their own trainings in a 'cascading' approach. In this way, 187,532 farmers gained access to structured IPM advice over the three years – a conservative estimate makes this approximately 20% of the total estimated number of maize farmers in Bangladesh. This was made possible through a direct project investment of roughly USD 4 per each farmer gaining access to FAW advice, demonstrating the power of what a relatively small investment in a strategically placed project can achieve when partnering with an effective scaling agency such as the government's agricultural extension department.

In addition, in an effort to boost women's standing in agricultural extension, as well as to provide a conduit for women extension agents to reach women-headed households and farmers with advice on FAW IPM, in November and December 2020 the project implemented a series of women-only trainings on FAW in collaboration with Bangladesh Wheat and Maize Research Institute in Chuadanga and Dinajpur, representing key regions for maize growth in southern and northern Bangladesh (Figure 8). To this end, 135 women DAE officials participated in hands-on, in-person trainings, marking what is hoped to be a watershed moment in empowering women extension agents in Bangladesh. Subsequent monitoring and evaluation efforts indicated that these women leaders shared what they learned about combatting FAW with a total of 2,530 other staff within the DAE, both through formal trainings in their working offices and also in informal engagements. A survey also suggested that this modality resulted in approximately 17,000 farmers receiving additional advice on IPM for FAW, with 23% of these farmers themselves being women or part of women-headed households.

Figure 8. One of four batches of DAE women: IPM Fall Armyworm leaders trained in November 2020 in Chauadanga and Dinajpur, Bangladesh.

To support these trainings, between September and October 2020 the project developed 13 video-based FAW IPM educational presentations in Bangla, for review, self-learning, and reflection by trainees and the general public. The duration of each video is 10–15 minutes. They follow the topics in Table 2 and are available via the links provided.

Table 2. Structured FAW IPM presentation videos released in Bangladesh

Video No.	Bangla language training video on FAW	Short description	Website link
1.	Fall Armyworm Introduction: Background, Identification and Monitoring	Background of FAW invasion, ways of identification and monitoring system of FAW in Bangladesh was described in this video. Total duration 10 min 32 sec.	https://youtu.be/s2xo05ftiac
2.	Risk of crop loss due to FAW infestation	Risk of different stages of maize crop by FAW infestation was described. Total duration 13 min 23 sec	https://youtu.be/biQxQc-rF5o
3.	Seedling scouting model for FAW infestation	Scouting procedures of FAW at the seedling stages of maize crops were discussed in this video. Total duration: 12 min	https://youtu.be/_Je8cPU5ydA
4.	Cob scouting model for FAW infestation (part 1)	Scouting procedures of FAW during cob stage especially just after tassel opening was described. Total duration: 6 minutes	https://youtu.be/rTR7-3b07Dk
5.	Cob scouting model for FAW infestation (part 2)	Scouting procedures of FAW during cob stage especially just after tassel opening was described. Total duration: 5 minutes	https://youtu.be/uoeYhpyTFfE

Video No.	Bangla language training video on FAW	Short description	Website link
6.	FAW Monitoring Instruction	In this video, FAW monitoring and scouting data entry procedures in tabs according to "Bangladesh FAW Monitoring Apps" was described. Total duration 10 min 21 sec.	https://youtu.be/Q52-6PmHpKQ
7.	Cultural and Biological management of FAW	Cultural and biological options for FAW management was described in this video presentation. Total duration: 13 min 11 sec.	https://youtu.be/oEE_VNxvB0o
8.	Biological keys and Fall Armyworm Management	In this video the biology of FAW and its relationship with its sustainable management was discussed. Total duration: 10 min 44 sec.	https://youtu.be/iq_gB_J39bk
9.	Moth Count and Fall Armyworm Outbreak (Part 1)	In this video the relationship between FAW population fluctuation data recording in pheromone traps and prediction of its outbreak was discussed.	https://youtu.be/j-zaJd-_Y10
10.	Moth Count and Fall Armyworm Outbreak (Part 2)	In this video the relationship between FAW population fluctuation data recording in pheromone traps and prediction of its outbreak was discussed. Total duration, part 1& 2: 18 min 22 sec.	https://youtu.be/z8v3o69WX0A
11.	Insecticide choices for Fall Armyworm Management	In this video choices of insecticides for FAW management were described.	https://youtu.be/oGrj-qPIqfE
12.	Insecticide choices for Fall Armyworm Management	In this video choices of insecticides for FAW management were described. Total duration, part 1 &2: 22 min.	https://youtu.be/rCtamQ9CpZU
13.	Fall Armyworm Agro-ecological Management	Agro-ecological management of FAW was described in this video presentation. Total duration 10 Min.	https://youtu.be/JIovOXI1n9c

4. Relevance of experiences to the regional FAW response

This section of the chapter reflects on key learnings relevant for improved FAW management across South Asia.

4.1. Better (regional) understanding of host plant resistance

Host plant resistance (HPR) must be made central to IPM strategies in order to achieve effective management of FAW in South Asia agroecologies and cropping system landscapes. Enabling HPR is economically sustainable, and depending on national seed systems policies and specifically in the case of conventional resistance, can be quickly scalable and deployable. In the case of native resistance, developing host plant resistance should in principle cost no more than normal hybrid seed (Prasanna, 2019). When HPR is coupled with other management tactics, it can significantly reduce insecticide use, and thus enhances the effectiveness of other complementary strategies.

CIMMYT's breeding efforts against major insect pests in the tropics, including Fall Armyworm, were initiated in the 1970s in Mexico, with FAW resistance identified in Caribbean maize germplasm and Tuxpeno germplasm (Prasanna, 2019). More recent successes have been achieved in screening maize germplasm for native resistance, with several suitable sources in white maize found which may be compatible with agroecosystems in Southern Africa (Prasanna, 2019), although it will take time for these materials to be made commercially available to farmers at a large scale. Unfortunately, no systematic evidence of HPR for FAW in the commercial or national maize lines grown in South Asia has yet been found.

Another strategy of developing host plant resistance to FAW involves stacking *Bacillus thuringiensis* (*Bt*) traits with different modes of action, although such techniques require careful planning to avoid the development of resistance (Midega *et al.* 2006; Huang *et al.* 2014), for example through the inclusion of refugia in agroecosystems (Karlsson Green *et al.* 2020).

However, regulatory and political barriers in South Asia need to be addressed before the development of *Bt* maize can be considered. These issues highlight the importance of a coordinated regional effort of screenhouse trials with artificial infestation with FAW to evaluate leading regional private sector maize hybrids for FAW tolerance and to identify sources of native genetic resistance (FAW tolerant hybrids). This will likely only be possible with strong private sector partnership at the regional level, and the focused support of donors to invest in identification of appropriate HPR in existing germplasm.

4.2. In the tropics and sub-tropics, monitoring is likely better than early warning systems

Fall Armyworm is a widely dispersing species (Day *et al.* 2017), already widely established in most countries in not only South Asia but also throughout the Asian continent (CABI, 2020). In sub-tropical and tropical South Asia, there exists a year-round habitat in the form of maize crops and alternative hosts that can accommodate the pest. Resident populations can therefore easily establish themselves, and new populations can easily migrate to and occupy the available niche presented by environments in tropical and sub-tropical South Asia.

Given the likely consistent presence of the pest, the value of early warning systems that have been championed by a range of international organizations and private firms may be somewhat limited. Conversely, what is needed are consistent efforts to monitor FAW population, incidence and damage dynamics. Coupled with estimates of economic injury levels, or even 'rules of thumb' to guide farmers in decision-making and advise when and where different management interventions are needed, such monitoring systems can provide consistent data for the practice of IPM. Point observations are only partially useful and early warnings are appropriate for less widely distributed or environmentally sensitive species (or in temperate environments). Rather, regular monitoring and time-series data that reveal trends in FAW population and damage severity are required.

4.3. Ecologically based management options

As a scientific discipline and approach to farm and cropping systems design, agroecology encourages the purposeful use of biological diversity and ecological interactions among species and their environment to optimize farm productivity, and also to effectively manage pests (Nicholls and Altieri 2016; Pretty 2003). In this sense, the application of agroecological principles in the management of invasive pests like FAW should focus on building and maintaining habitats for natural enemies, including arthropod predators, parasitoids, and even vertebrate predators (Harrison *et al.* 2019). Agroecological management of pests is however not sufficiently championed in South Asia, as many of the early national advisories that emerged following the invasion of FAW – including in Bangladesh – placed much focus on chemical management interventions, with less attention paid to fostering functional agroecosystem diversity to encourage pest suppression. This presents a missed opportunity to harness ecological services in support of cost-effective and environmentally sound pest management that can and should be addressed through future research and project activities.

4.4. Harness regional opportunities for data sharing and fast-track registration

Many parts of South Asia have similar agroecological and climatic conditions. However, each country has its own legislation and protocols regarding pesticide and bio-pesticide registration. Theoretically, data collected in Bangladesh could be extrapolated to adjacent areas in Nepal or in West Bengal, for example. Similarly, data collected in Uttar Pradesh in India could be applied to the adjacent province of Sudurpaschim in Nepal. However, standard research protocols and data collected in the different countries of South Asia are insufficiently shared. This presents a missed opportunity, as data on pest control product performance could be applied to analogous regions across South Asia, potentially assisting in the expedited registration of promising products that could be used to better manage invasive species. The sharing of well-designed and peer-reviewed research in SAARC member countries could include underlying datasets being made available for scrutiny and potential use as evidence for registration of less toxic but effective control products.

4.6. Standing regional and national task forces initialized to pre-empt invasive species

FAW will not be the last invasive species the region must contend with. Currently, many countries in South Asia manage invasive pests on a *reactive* rather than *pro-active* basis. This increases transaction costs, as pest task forces must be set up with each new invasive species detected. Also, the time required to set up a task force reduces the speed of a country's ability to respond effectively to a new pest threat. As such, SAARC countries could consider setting up and maintaining standing expert panels or a committee on invasive species, which should meet regularly and prepare protocols, approaches and systems to pro-actively manage future pests and crop disease. These groups can also serve to aid in raising awareness of IPM as an approach to managing invasive species, while also developing generalized training materials and systems to boost the capacity of extension services and the private sector in advance of new pest establishment. Such an approach would however require strong governmental backing and a modest budget, although it could potentially result in significant economic benefits being accrued by farmers if new invasive species can be effectively and rapidly controlled.

5. Conclusions

The invasive crop pest, Fall Armyworm, *Spodoptera fruigiperda* (J.E. Smith) (Lepidoptera: Noctuidae) which caused significant damage to maize crops in

Africa has also spread to South Asia. In Bangladesh, the government pre-emptively began efforts to plan for FAW in the months prior to its anticipated arrival. Alongside initiatives undertaken by the government, this chapter has provided lessons and learnings from the Fighting FAW project which enabled rapid response in the form of awareness-raising, monitoring, and assistance to the public and private sectors to better manage FAW .

Since the project's inception in late 2019, some of its key achievements have included the intensive training of a total of 825 government officials in FAW IPM, 31% of whom were women. In addition, a smaller sub-set of master trainers engaged in regular monitoring of FAW in farmers' fields, as well as coordinating their own trainings, 'cascading' new information to their peers. In sum, these actions resulted in 187,000 farmers receiving structured IPM advice on FAW. The project also developed three educational videos on FAW – which were shown in 197 *upazilas* (sub-districts) of 26 major maize growing districts through local cable television networks, reaching an estimated audience of 136,000 people – and developed and distributed a range of educational materials to 436,000 farmers.

Another strand of the project's work was to aid efforts to fast-track the registration of a biological pesticide for FAW. This was achieved through the awareness-raising of FAW National Task Force members and by lobbying the Plant Protection Wing of the Department of Agricultural Extension, as well as working closely with BARI to accelerate field trials to demonstrate the efficiency of the microbial pesticide SfNPV in FAW control. Through collaboration with agro-input company Ispahani Agro Limited, in 2020–21 this product was used by 4,000 farmers as an alternative to more toxic synthetic pesticides. In addition, CIMMYT and DAE worked collaboratively to develop a comprehensive population monitoring app and data dashboard (the Bangladesh Fall Armyworm Monitor), with monitoring of FAW populations and crop damage completed in the winter of 2019–20 and the 2020–21 season, in 777 maize fields across Bangladesh. Monitoring was also completed in the spring maize cropping season during *kharif* in 2020 and 2021 in 255 maize fields across 25 maize-growing districts. Continuous technical assistance provided to the FAW National Task Force on different aspects of FAW and national research and extension institutions also aided in responding to FAW.

Through presenting the learnings of this project, this chapter has provided several suggestions that may be of use in other SAARC member countries. These include (a) coordinated cross-national efforts to screen commercially available and early-research stage germplasm for host plant resistance, (b) increased focus on FAW population and damage dynamics monitoring as opposed to early warning systems (particularly in the tropics and sub-tropical regions of SAARC member countries), and (c) increased focus on the use of agroecological management principles to manage invasive species such as FAW. Finally, two coupled suggestions were provided, including (d) the establishment of standing multi-threat pest task forces in SAARC member states, which could (e) vet data and evidence from pest control product screening trials – which could be implemented using common protocols across countries – to aid in more rapid registration of biopesticides to aid in the management of invasive species. Although focused on FAW, these suggestions can also be applied to other pests and future invasive species that may affect SAARC member countries.

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Chapter 12

Eco-friendly management approaches of Fall Armyworm: Experiences and prospects in Bangladesh

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1. Introduction

The Fall Armyworm (FAW), *Spodoptera frugiperda*, a potentially damaging pest invaded Bangladesh in 2018 and established itself in different parts of the country as the environment is favorable for the insect. It has been documented to cause devastating damage in the crop Maize both in Robi and Kharif seasons for its high ability to multiply and quick spreading (Islam *et. al.,* 2019). Being transboundary and fast-spreading nature with high reproductive capacity and a wide host range, Fall Armyworm is likely to continue its spread and colonization especially in favourable habitat of the maize ecosystem in the country, and pose a great impact on the food security and livelihoods. Farmers usually apply readily available pesticides to overcome the problem of FAW. Unfortunately, the chemicals are often not effective (Prasanna *et al.*, 2018) and pose a significant risk to human health, biodiversity, and the environment. Fall Armyworm is reported to develop resistance to many common pesticides, including pyrethroids (Yu, 1991). Moreover, the application of highly toxic pesticides risks damaging the natural regulatory forces of the pest (Jahan and Islam, 2019). Pesticides should be used only when necessary and in an appropriate way. The Government of Bangladesh has initiated some measures since the arrival of FAW and formed a national task force to tackle the problem. Among others, Bangladesh Agricultural University with the support of KGF immediately discovered the invasion of the pest, looked into farmers' perceptions and developed and / modified some technologies for its management and also created awareness among many maize growers and stakeholders providing knowledge on identification, biology, ecology and technologies of control measures through training field days and workshops. The performance of the larval parasitoid *Bracon hebetor*, as well as various bio-rational control approaches were determined and fine-tuned to promote sound and sustainable Fall Armyworm management. This study compiles brief documentation on the current situation of FAW and natural enemies as a regulatory force and many other aspects of this particular pest to develop an IPM strategy on a short term and low-cost basis for smallholder farmers in Bangladesh. The research would also aid in a better understanding of supply-side bottlenecks and the collaborative development of measures to address the mismatch between agro-dealer demand for Bio-control agents and input industry supply.

2. Fall Armyworm incidence, damage and its natural enemy in Bangladesh

The Fall Armyworm (FAW), *Spodoptera frugiperda*, a damaging pest invaded Bangladesh in 2018 and established itself in different parts of the country as the environment is favorable for the insect. It has been documented in all the 64 districts of Bangladesh mainly in Maize but Cabbage and Napier grass were found to be attacked occasionally in some areas. It was reported to cause considerable amount of damage to the maize crop in the country. Summer maize crops suffered a lot from the attack of FAW. Incidence of the Fall Armyworm and occurrence of natural regulatory forces in the maize ecosystem studied in the farmers' fields in Chuadanga and Gaibandha districts of Bangladesh to describe the relationship between the pest and natural enemies.

Fall Armyworm starts to cause damage to maize within the week of germination and the damage is recognized by the windowpane appearance on the leaf, presence of first/ second instars' caterpillars and masses of excreta (Plate 1A). Generally, the damage becomes severe when plants reach to 6 leaf stage and increase up to 12 leaf stages (Plate 1B). The damage continues to maturity in the tassel/ cob formation stage, like an earworm (Plate 1C). Larvae feed on leaf tissue, making holes in them which is typical symptoms of the attack of Fall armyworm. Generally feeding on the young plant by Fall Armyworm through whorl may lead to a dead heart symptom. Older larvae can cause more significant damage and defoliation, leaving only ribs and stalks of maize plants giving torn or ragged appearance (Capinera, 2017; FAO, 2019).

Plate 1. Damage Symptoms of Fall armyworm

Infestation of FAW was investigated in Rabi and Kharif maize in 2019 and 2020 through scouting following "W" methods, observing 20 plants every week. Survey results indicate that infestation was common, although not causing severe damage in some fields. A higher incidence of fall Armyworm was found in Kharif than Rabi season, causing comparatively greater damage in Kharif maize. However, the damage intensity did not cross ETL in most cases probably for the presence of large number of natural enemies in the ecosystem (Table1).

Table. 1: Fall Armyworm and its natural enemy incidence and damage levels in maize at Chuadanga and Gaibandha districts of Bangladesh

Fall Armyworm & natural enemies	Robi season 2019-2020				Kharif season 2020			
	Chuadanga		Gaibandha		Chuadanga		Gaibandha	
	No./20 plants/ week	Damage (%)	No./20 plants/ week	Damage (%)	No./20 plants/ week	Damage (%)	No./20 plants/ week	Damage (%)
Pest								
Fall Armyworm	4.9	21.0	3.5	15.0	9.5	31.5	14.5	52.5
Natural enemies								
	No./20 plants/week		**No./20 plants/week**		**No./20 plants/week**		**No./20 plants/week**	
Spider	6.80		7.10		8.80		10.30	
Lady bird beetle	0.18		0.36		1.55		0.21	
Parasitoid	2.00		1.00		3.00		2.11	
Carabid beetle	1.09		1.54		0.50		0.68	
Ear wig	2.00		3.00		3.80		2.50	
Dragon Fly	0.00		0.00		0.40		0.00	
Damsel Fly	0.54		0.18		1.00		0.21	
Total	12.61		13.18		19.05		16.01	

Many predators and parasitoids are prevalent in the Fall Armyworm infested field. The common predators were spider, ladybird beetle, carabid beetle, damsel fly, dragon fly and earwig and a number parasitoid species were found in the field as regulatory factors to keep the population at a low level (Figure 1). The predators were documented to prey on the caterpillars of Fall Armyworm in the field. Spider was found as the dominant predator in all habitats both in kharif and Rabi seasons. There is similar evidence of natural enemies of Fall Armyworm infested field where a very unique correlation exists of among the pest population and natural enemies (Hruska *et al*, 1997).

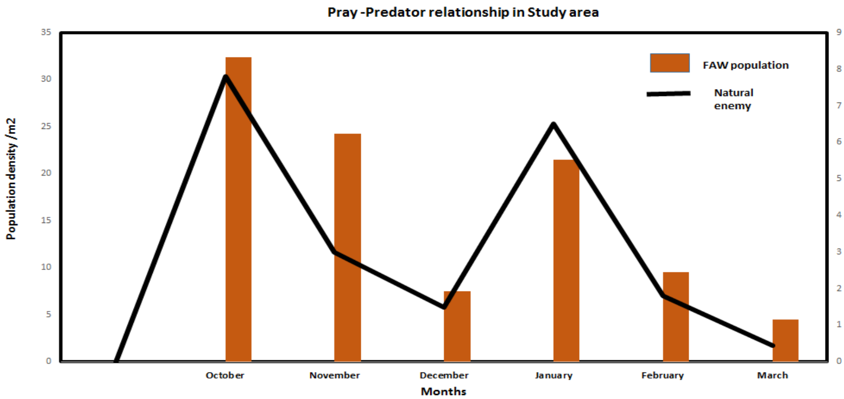

Figure 1. Relationship between Fall Armyworm and Natural enemy in an unsprayed field at Chuadanga district in Bangladesh.

Among the parasitoids *Bracon, Trichogramma, Archytas, Cotesia*, and *Chelonus* are the most prevalent species that attack the Fall Armyworm in Bangladesh (Table 2). The egg parasitoids of genera *Telenomus* and *Trichogramma* were common to attack FAW eggs. Direct predation and parasitism by the rich sources of natural enemies contributes to regulate the population of Fall Armyworm at low level in Bangladesh. However, in spite of presence of large number of natural enemy species, attack of FAW was common for its ability to reproduce in large numbers, migrate before seasonal conditions are suitable for predators and parasitoids and also for indiscriminate use of pesticides in some localities.

Table 2. List of Fall Armyworm parasitoids documented in major maize growing areas of Bangladesh

Sl. No.	Parasitoid species	Target host stage of FAW
1	*Trichogramma chilonis*	Egg
2	*Telenomus remus*	Egg
3	*Chelonus curvimaculatus*	Egg/ Larva
4	*Microchelonus heliopae*	Egg/ Larva
5	*Bracon hebetor*	Larva
6	*Archytas* sp.	Larva
7	*Campoletis flavicincta*	Larva
8	*Charops* sp.	Larva
9	*Cotesia* sp.	Larva
10	*Pristomerus* sp	Larva
11	*Apantales* sp.	Larva
12	*Amorpha* sp.	Larva
13	*Brachymeria ovata*	Pupa

3. Biology of Fall Armyworm

Fall Armyworm belongs to the family Noctuidae and Order Lepidoptera. Its life cycle of is completed in four stages viz., Egg, Larvae, Pupa, and Adult. Duration of life stages varies with the host plant (Table 2). Duration from egg to adult ranged from 32-45 days depending on the rearing environment and food supply. FAO (2019) reported a remarkable variation in its life duration as 30 days in summer and 60 days in winter. Stages of Fall Armyworm are described in respect of life duration and other parameters.

Egg: Female Fall Armyworm lays white dome-shaped eggs in clusters on either upper or lower surface of the leaf, base of the plant, and also in whorls of maize plant or cabbage leaf. A range of 950 to 1030 and 610 to 803 eggs were found to lay when it was reared on maize and cabbage respectively indicating maize is most suitable host for its multiplication. The incubation period ranged from 2-5 days with an average of 3 days. Similar incubation period was reported by Sparks *et al*., 2015; FAO, 2019; Hossain, 2020.

Plate 2. Egg masses of Fall armyworm

Larva: The larva had a set of four dark large spots on the upper surface of the last segment of its body that forms a square (Plate 3). The face or frons of the mature larva is marked with a white inverted 'Y' shape line, which distinguishes it from other caterpillars. Each larva passes through six distinct instars and completes larval stage in a period range of 14 - 22 days depending on the hosts available in Table 3. The larval period FAW tends to be about 14-30 days as reported by (Silva *et al*., 2017; Sharanabasappa *et al.,* 2018; CABI, 2019).

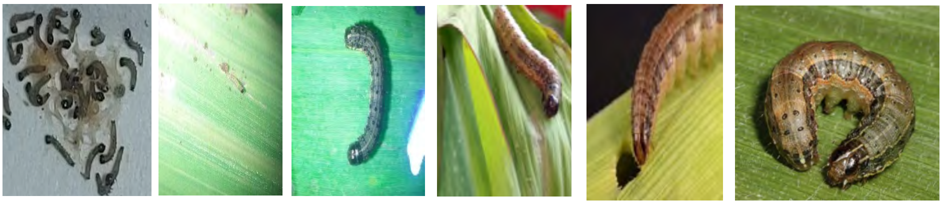

Plate 3. Six larval instars (1st to 6th in stars from left to right) of Fall armyworm

Pupa: The caterpillar once reached maturity falls to the ground to pupate in soil at a depth of 1-3 cm (Plate 4). Prasanna *et al.*, (2018) reported that the pupation occurs at higher depth. The duration of the pupal stage ranged from 9 to 15 days (Table 3). CABI (2019) reported a much longer pupal period of 20 to 30 days depending on season. The pupal stage of FAW cannot enter a diapause period to withstand protracted periods of cold weather or a dry season without host plants (Sparks, 1979).


A


B

Plate 4. Pupae of Fall armyworm. **A**- Pupa in mud cage, **B**- Pupal structure and shape

Adult: Adults are nocturnal and mostly remain active from evening. Generally, female moths are bigger in comparison to male moths. Adult moth wingspan is about 32- 40 mm (Plate 5). The adult phase lasts for about 7-13 days. The hind wing is silver-white with a narrow dark border in both males and females. The morphological characters of adults described here are similar with the report of CABI (2019). Pre-oviposition, oviposition, and post oviposition period ranged from 3-4, 2-3, and 4-5 days, respectively. After a preoviposition period of three to four days, the female normally deposits most of her eggs during the first two to four days of life. Duration of adult life is estimated to average about 10 days, with a range of about 7 to 13 days (Table 3). In captivity, each female laid an average of 950 when fed on maize plants. Fecundity female reared on cabbage was 710 eggs which is much lower than the female provided with maize leaf as diet. A very high percentage (95%) of egg hatchability was found with the female developed from maize diet. Sparks (1979) reported a brief account of the biology of fall armyworm.

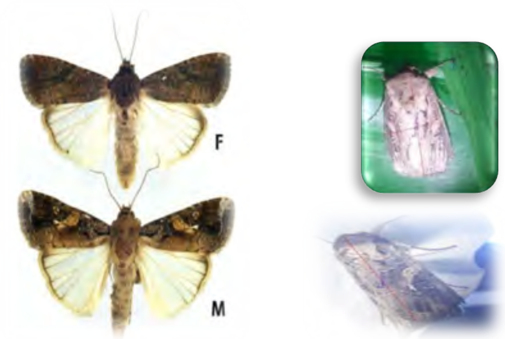

Plate 5. Male and female moth of Fall armyworm

Table 3. Biology of Fall armyworm, *Spodoptera frugiperda* reared on maize and Cabbage

Parameters/ Stages	Host plant of Fall armyworm			
	Maize		Cabbage	
	Mean	Range	Mean	Range
Fecundity (Number)	950.9±97.92	801 - 1130	510.90±97.92	610- 803
Egg hatchability (%)	94.90±1.31	93 - 97	82.90±1.50	75 - 87
Incubation period (day)	2.65±0.67	2 - 4	3.10±0.55	2 - 5
Larval period (day)	16.75±1.64	14 - 20	18.70±1.04	16 - 22
Pupal period (day)	10.70±1.48	9 - 14	14.70±1.24	9 - 15
Pre-Oviposition Period (day)	3.40±.50	3 - 4	3.60±.50	3 - 4
Oviposition period (day)	3.55±0.51	2 - 4	3.80±0.51	2 - 5
Post Oviposition Period (day)	4.50±0.51	4 - 5	4.00±0.51	4 - 5
Longevity of Male (day)	8.35±1.06	7 - 10	8.25± .26	7 – 9
Longevity of Female (day)	10.55±1.74	8 - 13	10.25±1.94	8 - 12
Egg to adult ♀ (day)	38.60±2.65	32 - 42	40.60±2.65	35 - 45
Egg to adult ♂ (day)	40.50±2.5	33 - 44	40.30±2.50	33 - 45

The biological studies demonstrated that the invasive Fall Armyworm species is succeeding quite well in the environment Bangladesh exhibiting similar attributes as typical in Africa. The present study provides basic information about the biology and external morphology of FAW in the context of Bangladesh. It is known that FAW has a high host range of about 80 plant species but all the species might not be equally suitable host. In the present investigation a remarkable change in the biological parameters was evident when Fall Armyworm develops in the host plants maize and cabbage (Table 3). Although the pest FAW uses many host plants for its survival, the present findings highlights that there would be some changes in life parameters when exposed to other host plants.

4. Feeding indices of fourth instar larvae of *Spodoptera frugiperda* at different diets

The Consumption Index (CI), Relative Growth Rate (RGR), and Approximate Digestibility (AD) were significantly lower (Mann-Whitney *U* Test, $P < 0.001$ (Minitab 20) in cabbage fed FAW larvae compared to its regular host 'maize.' Nevertheless, the higher fecundity and more female bias sex ratio of Fall Armyworm on maize indicate it as a suitable alternate host plant. It may cause economic damage under certain circumstances. Insights on the cabbage as a new host of FAW are discussed (Table 4).

Table 4. Feeding indices of fourth instar larvae of *Spodoptera frugiperda* at different diets

Treatments	AD (%)	ECI (%)	ECD (%)	RCR (mg/mg/day)	RGR (mg/mg/day)
Maize cob	73.80 ± 0.42 a	12.70 ± 0.30 c	15.44 ± 0.27 b	1.41 ± 0.04 b	0.20 ± 0.01 b
Cabbage	75.5 ± 0.65 a	10.71 ± 0.76 c	12.5 ± 0.88 b	0.89 ± 0.07 c	0.10 ± 0.01 c
Maize leaf	62.5 ± 0.70 b	18.34 ± 0.44 b	18.00 ± 0.52 c	1.9 ± 0.06 a	0.30 ± 0.01 a

Means ± standard deviation followed by the same letter within columns indicate no significant difference (Student-Newman-Keuls test: $P < 0.05$). RGR- Relative Growth Rate, RCR - Relative Consumption Rate, ECI - Efficiency of Food Ingestion, ECD - Efficiency of Food Digestion, AD - Approximate Digestibility

5. Management strategy of Fall Armyworm

5.1 Effect of the parasitoid *Bracon hebetor*:

The parasitoid *Bracon hebetor* is an important parasitoid of many Lepidopteran insect including the invasive pest Fall armyworm. It inserts the egg inside the body of larva (Plat 5). It showed distinct parasitization preference for different larval instars of FAW. The 2nd and 3rd instar larvae were less preferred for parasitization to those of 4th and 5th instar larvae. Maximum egg deposition occurred the 5th instar larva (Figure 2). It is in conformity with the earlier finding Islam *et al.*, (2019). With a view of overall effect of *Bracon hebetor* on Fall armyworm, based upon the percent reduction over control, a maximum reduction 40.26% was evident (Table 5). Numerical response indicates that with increasing number of *Bracon hebetor* per unit area more reduction of the pest population in the field is possible using this biocontrol agent.

Plate 6. The parasitoid, Bracon hebetor is ovipositing on larva of Fall armyworm

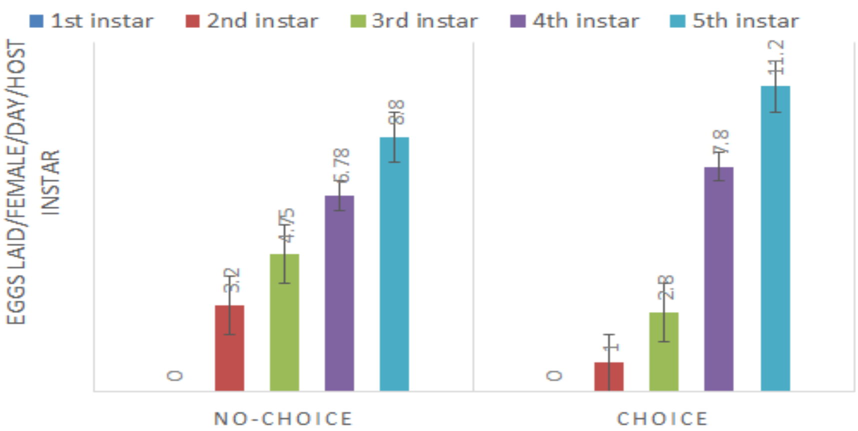

Figure 2. Mean daily fecundity of Bracon hebetor in different instars of Fall Armyworm in choice and no-choice test

Table 5: Effect of *Bracon hebetor* on the management of Fall Armyworm during Rabi season at Chuadanga.

Treatments	Mean percentage of infested plant at different time intervals of *Bracon* release				Cumulative mean	Reduction (%) of the infested plant over control
	Pretreatment	7 DAT	14 DAT	21 DAT		
T_1= *B. hebetor* @ 2 adults/ plot	32.14 a	32.08 a	31.31 b	30.37 b	31.25 ab	15.30
T_2= *B. hebetor* @ 5 adults/ plot	31.92 a	31.61 a	29.56 b	26.12 b	29.10 b	21.15
T_3= *B. hebetor* @10 adults/ plot	29.93 a	28.87 a	23.13 c	14.13 c	22.04 c	40.26
T_0= Control (Untreated)	30.67 a	32.56 a	36.87 a	41.27 a	36.90 a	
Level of significance	NS	NS	P≤0.01	P≤0.001	P≤0.01	

In the column, means followed by different letters are significantly different, NS= Non-significance, DAT= Day After Treatment

5.2 Effect of the microbial pesticide Spodoptera Nucleo polyhedron virus (SNPV)

5.2.1 Laboratory Bioassay of SNPV against Fall armyworm

Results showed that higher concentrations had given the highest mortality when treated with SNPV alone in a diet mixed method (Table 6). It was also observed that the effectiveness of SNPV increased with time. Mean maximum mortality was 70.33% with the highest concentration of 0.3g/L water. The highest mortality percentage of fall Armyworm with the dose of 0.3g/L SNPV is in support with report of Hossain (2020). He also mentioned that there was no significant difference in effect between the dose of 0.2g/L and 0.3g/L but in the present study the effect of doses of SNPV was significantly different. No attempt was made to comparison with SFNPV as it was not available in study period but recently it is available in Bangladesh.

Table 6. Efficacy of SNPV in Lab on the mortality of Fall armyworm, *Spodoptera frugiperda* at temperature 24-26^0 C and 60-70% RH.

Treatments	**Percent Larval Mortality (±SEM) different time interval**		
	48 hrs	**72 hrs**	**96 hrs**
T_1 = SNPV @ 0.1 g/L water	8.00±2.44 b	25.00±2.44 c	36.67±5.77 c
T_2 = SNPV @ 0.2 g/L water	18.00±2.00 a	36.00±4.00 b	56.5±6.5 b
T_3 = SNPV @ 0.3 g/L water	22.00±2.00 a	48.00±3.74 a	70.33±5.77 a
T_0 = Control (Untreated)	0.0 b	0.0 d	0.0 d
Level of significance	P≤0.01	P≤0.01	P≤0.01

*Means within a column not sharing a common letter indicate significant differences at 5 % level of probability. Means were separated by Tukey's test

5.2.2 Efficacy of some microbial pesticides against Fall Armyworm in the field

The experiment conducted with four microbial pesticides *viz.* Nuclear Polyhedrosis Virus (Spodo-NPV) @ 0.2g/L, *Bacillus thuringiensis* (Bio bit) @0.4g/L, *Beauveria bassiana* (BABA) @ 1ml/L and *Metarhizium anisopliae* (Green META) @8g/L at Chuadanga district during Rabi season showed the comparative efficacy of four microbials of different mode of action against fall armyworm, *Spodoptera frugiperda* under farmer's field condition. Percent infestation of leaves by the pest was significantly different with the application of the biopesticides of different origin. The mean percentage of range of 33.59 to 27.35% leaf infestation was evident. The results clearly revealed that different treatments with the microbes had a significant effect on the leaf infestation and the effect was clearly also dose and time-dependent (Table 7). A significant level of leaf infestation was found at 3 DAT which further increased at 7 DAT and 14 DAT. Control treatment (T_0) showed the highest o 41.16% percentage of leaf infestation which was followed by 26.42%, 23.76%, and 19.61% *Beauverria bassiana*, *Bacillus thuringiensis* (Bio bit) and Nuclear Polyhedrosis Virus (Spodo-NPV) respectively whereas the lowest (15.42%) leaf infestation was found with the treatment of *Metarhizium anisopliae* indicating its high potentiality to control Fall Armyworm on the field.

Table 7: Field evaluation of different microbial pesticides against Fall armyworm, Spodoptera frugiperda during Rabi season in Chuadanga.

Treatments	Mean percentage of infested plant at different time intervals of treatment				Cumulative mean	Reduction (%) of the infested leaf over control
	Before application	3 DAT	7 DAT	14 DAT		
T_0 Control	32.24ab	33.44a	36.32a	41.16a	36.86a	
T_1 Nuclear Polyhedrosis Virus (Spodo-NPV) @ 0.2g/L	27.35c	25.17b	21.63cd	19.61cd	22.14c	39.95
T_2 *Bacillus thuringiensis* (Bio bit) @0.4g/L	28.81c	27.12b	25.65cd	23.76bc	25.51bc	30.80
T_3 *Beauveria bassiana* (BABA)@ 1ml/L	30.41abc	29.62ab	28.67ab	26.42b	28.24b	23.40
T_4 *Metarhizium anisopliae* (Green META) @8g/L	33.59a	30.15a	18.86ab	15.42b	19.59b	52.02
Level of significance	NS	$P\leq0.05$	$P\leq0.001$	$P\leq0.001$	$P\leq0.01$	

In the column, means followed by different letters are significantly different, NS means non-significance. DAT=means Day after treatment.

From the result of a cumulative mean of infestation, the highest infestation of 36.86% was observed in the control treatment whereas the lowest (22.14%) infestation was recorded in (Spodo-NPV) @ 0.2g/L. With a view of the overall effect of biopesticide on fall army warm of maize, based upon the percent reduction of fall army warm over control, the highest percent reduction of leaf infestation was 52.02% followed by 39.95% with SNPV @ 0.2g/L, and 30.80% with *Bacillus thuringiensis*, whereas the lowest reduction of leaf infestation was recorded in *Beauveria bassiana* treated plants. The local strains are available which could be explored for isolation and characterization and efficacy against FAW promoting sustainable farming system.

5.3 Field efficacy of different new molecule insecticides against Fall Armyworm

Efficacy of some new molecule insecticides was determined in the field observing the level of leaf infestation by Fall Armyworm after seven days of pesticide application. The change in the level of leaf infestation at different time intervals due to the effect of new molecule insecticide is presented in Table 8. The mean percent of leaf infestation differed significantly among the treatments ($P\leq0.01$).

Table 8: Effect of five new molecule insecticides on the reduction of infestation by Fall armyworm, *Spodoptera frugiperda*

Treatments	Mean percentage of the infested leaf				Cumulative mean	Reduction (%) of the infested leaf over control
	Before Spray	1 DAT	3 DAT	7 DAT		
T0= Control	35.07a	37.543a	40.66a	46.23a	41.70a	
T1= Thiamethoxam 20% + Chlorantraniliprole 20% (Volium flexi 300 SC) @ 0.4g/L	36.27a	32.83b	30.25bc	27.41bc	30.16bc	27.67
T2= Lufenuron (Hayron 5 EC) @1ml/L	34.73a	33.41ab	31.55b	29.34bc	31.43bc	24.62
T3= Chlorantraniliprole (Coragon 20 SC) @ 0.4ml/L	36.03a	34.26ab	29.9bc	22.67cd	28.94bc	30.59
T4= Emamectin benzoate 5 SG (Hayclacium 5 SW) @1g/L	34.28a	32.14b	27.81c	20.12d	26.69c	35.99
T5=Profenofos 40% + Cypermethrin 2.5% (Shobicron 425 EC) @ 0.4ml/L	34.57a	33.82ab	32.59b	30.39b	32.27b	22.62
T6= Flubendiamide (Belt 24 WG) @ 2.0g/L	34.15a	33.563ab	32.55b	29.89b	31.89b	23.52
Level of significance	NS	NS	***	***	***	

In the column, means followed by different letters are significantly different. ***means at 0.1% level of probability, NS means non-significance. DAT=means Day after treatment.

Application different insecticides to the Fall Armyworm infested field showed significant effect on the level leaf infestation (Table 8). The highest leaf infestation was 41.70% in the control treatment whereas the lowest infestation was 26.69% in the treatment with Emamectin benzoate 5 SG (Hayclacium 5 SW) @1g/L. Result showed the reduction of infested leaf over control as 35.99%, 30.59%, 27.67%, 24.62%, 23.52% and 22.62% with the treatment of Emamectin benzoate, Chlorantraniliprole, Thiamethoxam 20% + Chlorantraniliprole 20%, Lufenuron, Flubendiamide, and Profenofos 40% + Cypermethrin respectively. With a view of the overall insecticidal effect on fall Armyworm of maize, based upon the percent reduction of infested leaf over control, the field test indicates the higher efficacy of Emamectin benzoate and chlorantraniliprole against FAW. Chlorantraniliprole and Flubendiamide are recently introduced new molecule insecticides known to have some selective properties were evaluated for their toxicity to spider, the most common natural enemies in the maize ecosystem.

Table 9. Toxicity of three insecticides to common predator the spider, *Lycosa barnesi*

Natural enemy	Insecticides	Slope ± SE	LC_{50} (mg a.i. liter^{-1})	95% confidence limits	RQ[a]	Category[b]
Spider	Chlorantraniliprole	1.94 ± 0.21	0.24	0.20~0.29	9.38	1
	Flubendiamide	1.55 ± 0.19	22.77	17.91~28.71	0.66	1
	Carbosulfun	2.12 ± 0.22	0.029	0.025~0.035	775.86	2

RQ[a], risk quotient = recommended field rate (g a.i. ha^{-1})/LC_{50} (mg a.i. liter^{-1}).

Category, 1: safe; 2: slightly to moderately toxic; 3: dangerously toxic.

Toxicity comparison of two new generation insecticides and carbosulfun a commonly used one to spider, the most prevalent natural enemy in the maize ecosystem in Bangladesh was documented (Table 9). It indicates that the new generation products are less disruptive to natural enemies for which these insecticides would be of better choice for integrated management of FAW in maize ecosystem of Bangladesh. Integration with safer insecticides like Diamide product with slight or moderate toxicity to natural enemies would always be emphasized for the successful management Fall Armyworm and conservation of biodiversity to provide a better environment for living being.

6. Capacity building programs

Training programs and field days were conducted in Chuadanga, Gaibandha and Mymensingh districts for capacity building and awareness development providing them knowledge with the technologies developed and information available. Knowledge on the Fall Armyworm and its management technologies was also disseminated through ATN Bangla and Jamuna TV channels. Some technologies of pest management were disseminated through development and dissemination of communication materials like the training manual and leaflet (Plate 7).

Plate 7: Perspectives of training sessions and field days on FAW management at Chuadanga

7. Conclusions

- A good number of promising parasitoids and predators were documented as natural regulatory factors of Fall Armyworm in different locations in Bangladesh. Nonetheless, natural regulatory forces are sufficient; but there should be some management for modification and deployment to make them more effective.
- Method Sex pheromone trap and regular visual count can be a tool for estimating incidences and early warning of FAW.
- Biological observation revealed some basic facts about the Fall armyworm's life cycle as well as a number of physiological traits that are significant in pest management decisions.
- The bio-control agents such as entomopathogenic bacteria, fungus, viruses and parasitoid caused a significant reduction of FAW population and damage need to be incorporated as promising tools of its eco-friendly management. Local strain of pathogens should be explored for sustainable management.
- The insecticides Emamectin benzoate, chlorantraniliprole and flubendiamide showed higher efficacy against FAW. However, use of diamide product need to be emphasized in IPM of FAW for less disruptive effect to natural enemies.
- A number of farmers are now familiar with the pest Fall armyworms and its management strategy through participation in different awareness development programs. Further programs for capacity building is required to combat this invasive pest successfully.
- Indigenous and local tools should be promoted, and safer pesticides should be registered. Research on biocontrol should be strengthened and low-cost protocol for mass production of bio-control agent should be implemented. A nationwide Strong Action Plan for Fall Armyworm is essential to protect people's livelihoods.

8. Acknowledgements

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Report of the regional consultation meeting on Fall Armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith) - the status, challenges and experiences among the SAARC Member States

(27-28 January 2021)

The Regional Expert Consultation Meeting on "Fall Armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith) - the status, challenges and experiences among the SAARC Member States" was held on 27-28 January 2021. It was organized by SAARC Agriculture Centre (SAC) on a virtual mode and the National Focal Experts from all eight SAARC Member Countries have participated in this important meeting. The Director of SAARC Agriculture Centre, Dr. Md. Baktear Hossain cordially welcomed the participants and emphasized the importance of the meeting as Fall Armyworm (FAW) is an invasive pest severely affecting some of the important crops and their production in South Asia. Mr. Abdur Rouf, Additional Secretary, Ministry of Agriculture, Bangladesh graced the occasion as Special guest during the inaugural session. In absence of Chief Guest, Dr Sreekanth Attaluri, Senior Program Specialist (Crops) delivered the speech of Chief Guest Mr Md. Mesbahul Islam, Secretary, Ministry of Agriculture, Government of Bangladesh during the opening session of the meeting. The Chief Guest conveyed the important role played by SAC in coordinating and creating common platforms for the experts of the region to share their knowledge and experiences and to disseminate the information particularly on the effective control of Fall Armyworm in the region. Mr Rouf also emphasized the need to control the trans-boundary pests, sharing of technologies developed by Entomologists of various research institutes, as well as to prepare necessary strategies to cope up the increased demand for food during the COVID 19 pandemic in South Asia. The contributions made by the SAC in disseminating agricultural technologies and sharing of information was highlighted. The technical partner institutions participated were CIMMYT, CABI and FAO. During the two days meeting, National Focal Experts have shared the information and experiences of prevalence of Fall Armyworm and discussed on the need to take preventive measures regarding the entry of Fall Armyworm in countries that have not seen the pest attack so far in South Asia. Necessary technologies that can prevent the spread of the pest to the new areas, were thoroughly discussed, and aspects of biological control and research studies conducted / pest survey information was shared by respective countries. In addition, experts also presented the research investments needed for further studies on Fall Armyworm control which can support the farming communities for taking up necessary preventive measures and for improving their rural livelihoods. The meeting was highly interactive and discussions were fruitful as intended to achieve the objectives of the meeting. Based on the country status papers presentations and discussions during the meeting, key recommendations have emerged from the meeting for consideration by SAARC member countries for control of Fall Armyworm through an effective mechanism and approach in the region.

Objectives:

- To share the challenges and status of FAW prevalence among the SAARC countries.
- To present the latest scientific results on all aspects of IPM research of FAW with a special focus on status of biological control and other environmentally sound strategies for FAW management.
- To develop a SAARC FAW network coordinated through SAC.

In the closing session, Director of SAC thanked all National Focal Experts for their time and energy that they have spent in gathering information, compiling, analyzing and finally formulating in the form of presentations and country papers. In the programme on the inaugural day, Dr. N. Bakthavatsalam-Director, National Bureau of Agricultural Insect Resources (NBAIR), ICAR, India chaired the technical session-1 followed by Dr. Khandakar Shariful Islam, Professor, Dept. of Entomology, Bangladesh Agricultural University for the technical session-2. Dr. Md. Baktear Hossain, Director SAARC Agriculture Centre chaired the technical session-3 on the second day. The recommendations were finalized during the meeting. Dr. Sreekanth Attaluri, Senior Programme Specialist (Crops) coordinated the entire programme.

Papers Presented

A total of eight country papers on 'Fall Armyworm – the status, challenges and experiences among the SAARC Member States' were presented at the regional consultation meeting covering Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka. Three invited/technical papers from CABI, CIMMYT and BAU were presented covering crucial aspects of Fall Armyworm in South Asia.

Recommendations

The salient recommendations emerged during the consultation meeting are highlighted below

1. Strengthen surveillance, research and extension of FAW on maize and potential non-maize host crops while developing biologically intensive integrated pest management (IPM) programs against FAW.

2. Support the evolution of national FAW task forces into standing cross-sectorial invasive pest species committees capable of developing strategies and action plans for respective SAARC Member States.
3. Establish mechanisms to communicate uniform FAW management recommendations through appropriate disseminating channels in rural areas of SAARC Member States.
4. Appropriate seed treatment should be popularized against FAW and approved seed treating agents should be made available to farmers.
5. Bilateral and / or multilateral MoU's among SAARC Member States should be developed for exchange of information, capacity building and bio-control agents in line with the Nagoya protocol on Access and Benefit Sharing (ABS).
6. Stable FAW tolerant/resistant genotypes should be identified and exchanged in collaboration with International organizations and between SAARC countries developing cultivars with native genetic tolerance or resistance.
7. Build local capacities in SAARC Member States for extension personnel and maize / non-maize growers in partnership with local and International organizations.
8. Develop appropriate, demand-driven and common digital tools for monitoring, advisory, and forecasting of FAW.
9. Develop mass production protocols for biopesticides and the multiplication of bioagents at the community level and above.
10. Natural enemies of FAW from similar agro-ecological zones may be collected and catalogued for the sharing of information on potential for FAW control among SAARC Member States.
11. SAC is recommended to act as coordinator for collaborative research and to facilitate the exchange of information across Member States in technical partnership with National and International organizations.
12. FAW response networks should be strengthened among the SAARC Member States through FAW projects, institutions, and nominated nodal persons from each SAARC Member State to share data on the status of FAW and appropriate IPM technologies, which may also be linked to the SAC web portal.
13. The harmonization of registration of biopesticides across Member States and SAC coordinates through consultation meetings of members of respective pesticide registration committees is recommended.
14. The concerned agencies of Member States to consider emergency licensing of bio-agents (where one country already registered the bio-agent) and in order to send to other Member States.

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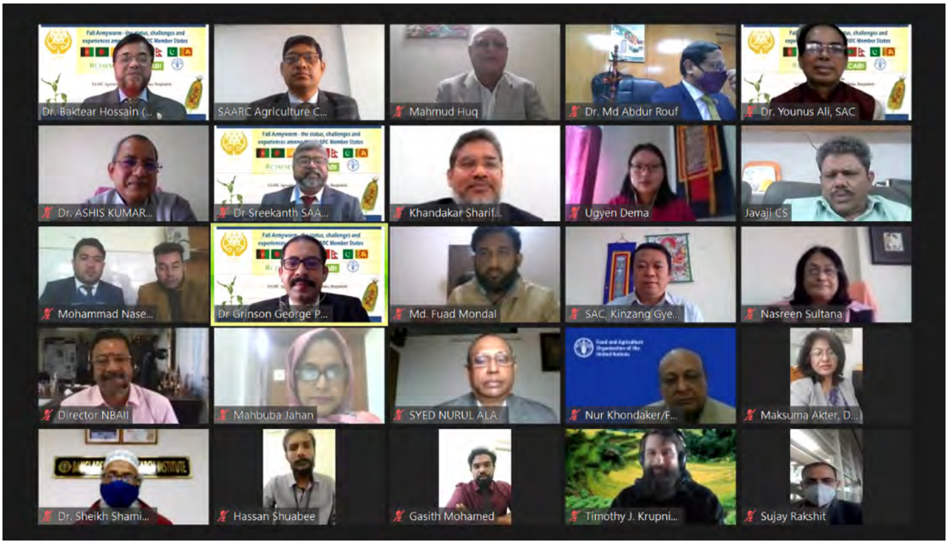
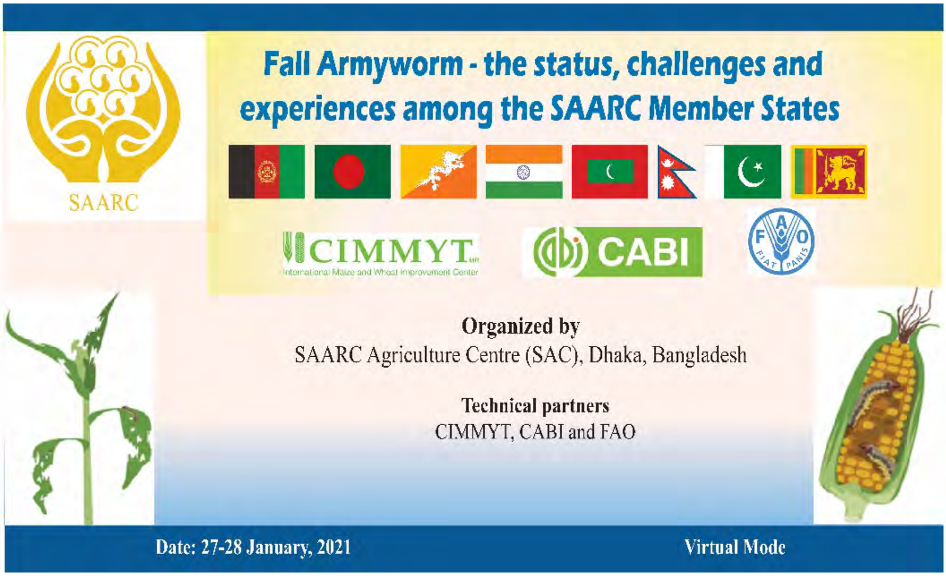
CONSULTATION MEETING PHOTOGRAPH





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